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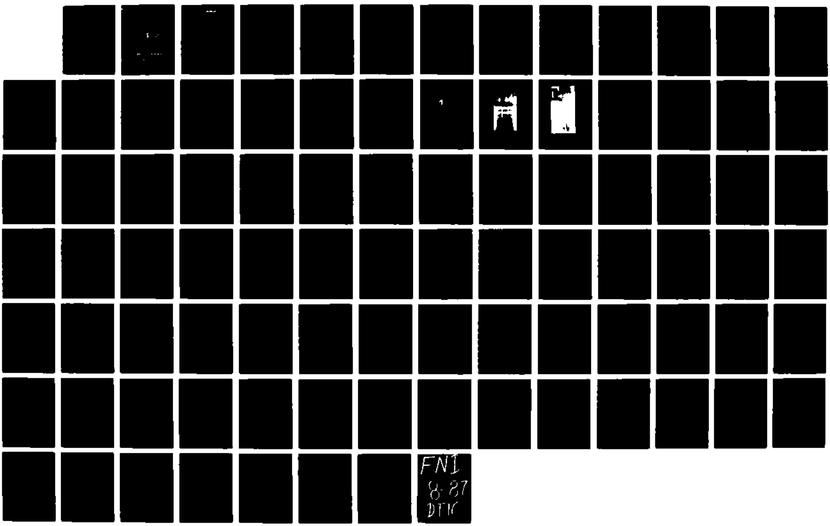

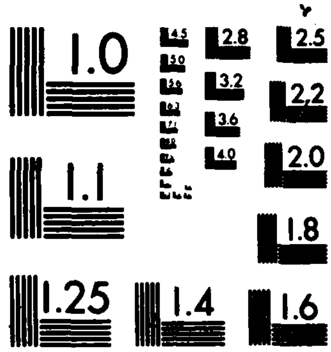

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IMPLEMENTATION OF INVERSE MULTIPROFILE STREAK TECHNIQUE

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The inverse multiprofile streak technique is a new measurement technique available to researchers and was implemented to better achieve measurements on detonation phenomena. This technique provides the wave front geometry around the perimeter of an explosive charge through the use of multiple slits placed on the charge and a high speed streak camera. Testing and analysis and methodology for this technique are presented in order to provide information to interested researchers. A personal computer program and sample tests are included to illustrate the methods used.

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ACKNOWLEDGMENT

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INTRODUCTION

The inverse multiprofile streak technique is a method that provides information on the detonation wave front's Geometry around the perimeter of an explosive charge. This is achieved by placing multiple slits, in the form of dark and clear horizontal bands, around the perimeter of the charge. The detonation is then observed with a high speed streak camera. The film results yield the time the detonation wave front passes each intersection between the dark and clear bands. The orientation of the detonation wave can be determined from the time of arrival data.

This technique was previously published by its developers (ref 1). Their paper did not discuss the details of the testing or the analysis used. This report details our implementation of the technique and our analysis of multiple tests was made easier by interfacing a motion analyzer with a personal computer. A program listing is included in the appendix. The objective of this report is to make the inverse multiprofile streak technique readily available for use in the development programs.

Keywords; Ultra high speed photography; Streak photography; explosive testing.

TEST METHODS IN STUDYING DETONATIONS

Over the years, many testing techniques were developed to enable the scientist to characterize detonation phenomena. Two properties in which researchers are interested are: the detonation propagation velocity and the detonation front geometry. These properties are the easiest to measure. Several techniques that enable the researcher to simultaneously measure the detonation velocity and geometry are flash x-ray, ionization pins, and ultra-high-speed photography.

Flash x-ray tubes emit a cone of higher power x-ray radiation of very short duration that can obtain a still picture of a fast moving detonation event. By using a soft x-ray tube that emits a large proportion of low energy x-ray radiation, the slightly denser shock front of the detonation wave can be captured on film (ref 2) (fig. 1). Quality results are very difficult to obtain, because the absorption of x-ray radiation at the detonation front is only slightly greater than that of the detonated or undetonated charge. The photographs obtained are a projection of the full view onto a plane that sometimes obscures much of the shock and reaction front's fine structure.

Multiple views at different times are required for detonation velocity measurements. The number of views with a flash x-ray system are limited by the capacitor banks, which supply the power for the tubes, and by the flash x-ray tubes. The capacitor banks require time to recharge after each test, necessitating one capacitor bank for each view obtained. The flash x-ray tubes are not durable when used repetitively within short intervals. For multiple testing times, separate pairs of x-ray tubes and capacitors are required. This severely limits the number of views obtained as well as complicates the analysis since each view is taken from a separate angle.

The electrical conductivity of the ionized products behind the detonation front was used in characterizing detonation waves. Ionization pins inserted into the surface of a test sample are charged with an electrical potential that is shorted by the passing conductive ionized products. With a simple electrical circuit and a fast time recorder or oscillascope, the arrival times of the detonation wave front can be measured. If the ionization pins are placed circumferentially and longitudinally within a test sample, the arrival time of the detonation wave at each pin location can be recorded (fig. 2). With the location of each pin, the orientation and velocity of the detonation front can be calculated. The technique is accurate, but suffers two major drawbacks. A complete measurement on a complicated test piece requires many ionization pins and many time interval meters or very fast oscilloscopes, both are very expensive. The pins also require an electrical circuit attached to them, which poses an additional safety hazard around explosive charges.

Ultra-high-speed photography does not pose this risk of accidental initiation, and can inexpensively obtain more complete data by viewing and testing a larger area of the charge. Two basic types of ultra-high-speed cameras are available: the framing and streak cameras. Framing cameras that can record individual frames or pictures at rates of millions of frames a second are available. The cameras are very limited in the number of frames obtained (about 25 frames). Generally, the results are easily analyzed because the researcher can clearly observe the event on the film. The detonation front geometry of the charges perimeter is viewed directly, while multiple frames can be used to compute the detonation velocity.

Framing cameras are limited to providing data at discrete points in time, which can be a disadvantage when studying events that vary continuously, as in varying detonation front geometries or detonation velocities in nonuniform charges. For this reason, streak cameras were used effectively in studying detonation phenomenon separately and in conjunction with framing cameras.

A streak camera quickly sweeps the image of the event over the film by either rotating the film in a drum or reflecting the image off a rotating mirror onto the film (fig. 3). High image sweep speeds of 20 mm/μ are possible in many cameras. Because the film is constantly being exposed by the image, some means must be used to prevent an event at one time and position from obscuring an event at another. The most common means is limiting the size of the image that is exposing the film by either inserting a slit perpendicular to the film sweep at the image plane in the optical system, or by placing a slitted mask directly upon the charge. The film results yield the time that a luminous event occurs at each position along the slit. With the proper placement of the slit, a large variety of information can be obtained with a streak camera. These can be separated into three catagories: detonation velocity, time of arrival at a specific location, and detonation wave profile measurement.

The streak camera is ideally suited for determining the instantaneous detonation velocity of a charge. By placing the slit along the axis of a charge, which is then detonated, the resulting image obtained is a line with slope equal to a scaled detonation velocity (fig. 4). This is a common use of the streak camera. This method does not yield any information on the detonation wave form within the explosive; it requires other techniques.

Two types of ultra-high-speed streak photographic test methods available that yield information on the detonation wave geometry are: the arrival time measurement and the detonation wave profile measurement (ref 3) (fig. 4). In the arrival time measurement, the slit is placed along the surface farthest from the initiation of the explosive charge. This allows the arrival or breakout time of the detonation wave at this surface to be determined. This method yields the breakout history of the detonation wave along only one line on the horizontal plane of the base. Multiple horizontal slits have also been placed on the base of the charge to increase the information obtained. The geometry of the detonation wave cannot be determined without knowing the detonation velocity. To obtain detonation velocities simultaneously on the charge, mirrors can be used to obtain a side view of the charge during testing.

In the profile test, the slit is placed perpendicular to the axis of the charge, yielding the profile of the detonation wave as it passes the slit. If the detonation velocity is known and the intersection of the detonation wave and the perimeter of the charge lie in a plane, the tilt of the wave from the central axis can be determined.

The inverse multiprofile streak technique, developed by Held and Nikowitsch (ref 1) and studied in this paper, is a variation on the profile technique (fig. 5). In this test, the slit is removed from the streak camera and placed around the charge. The slit takes the form of horizontal clear and dark bands placed on flexible film or acrylic tubing. This allows the use of multiple slits which are the intersections between the dark and clear bands. The detonation velocity can also be determined by measuring the time required to pass each band.

By reflecting the image off a pair of mirrors, the camera can view a full 360 degrees around the perimeter of the detonating charge. This assures that the measurements on the wave tilt are not unduly influenced by any irregularities in the detonation wave structure.

EXPERIMENT

Two test devices were used to verify the analysis. Each had a 1-inch diameter by 1-inch tall TNT charge with a 1/2-inch diameter by 1-inch tall TNT booster pellet initiated with an RP-2 Reynolds Corporation exploding bridgewire detonator. The first test was initiated with the booster centered on the charge. The second test placed the booster 1/4-inch off center at 90 degrees from the front of the image. The pellets had a low density averaging 1.548 gm/cm^3 for the charge and 1.487 gm/cm^3 for the booster pellets. TNT crystal has a theoretical maximum density of 1.654 gm/cm^3 (ref 4). Previous work indicated very large wave tilts when a booster was not used. The booster pellet provides a section of explosive which allows the detonation wave front to expand and become more planar. The charge is wrapped in a mask made of Kodak brand Ektachrome film with alternate transparent and opaque horizontal bands. The original for the film wrap was drawn in ink on paper that was copied with a photographic reproduction process. These methods obtained quality reproduction on the film with high contrast. Vertical marks were placed on the film as reference marks.

Since the bands were originally hand drawn, variations were expected from the nominal 0.1 inch (2.54 mm) between bands. For this reason, the heights of each band were measured by means of microscope. The measured heights were 5.799, 8.420, 11.280, and 14.691 mm as measured from the upper edge of the charge and were used in the analysis.

While detonations are luminous events, they are not bright enough to expose film at very high writing speeds. To produce a brighter light, a small controlled air gap is left between the film and the charge. When the detonation passes the small air gap, it shock heats the air which becomes luminous. Drafting tape was placed on the inside of the film, along the dark bands, in order to obtain a controlled air gap 0.13 mm thick.

When the film is wrapped around the sample, the upper portion is placed tightly against the plate that aligns the booster to the charge. Scotch tape is used to hold the film tightly around the charge. Earlier tests indicated that the film by itself is not strong enough to stay tightly wrapped during detonation. For this reason, a section of clear film is wrapped around the charge to hold the assembly together during testing.

Flat front surface mirrors (4 to 6 waves/inch flat, 1/8-inch thick) were used to observe the event. The mirrors were epoxied to plywood triangles that supported the mirrors perpendicular to the test stand. Because of the destructive nature of the tests, plywood boards were used for the test platforms.

The alignment of the event to the camera system is critical. If the charge lies above or below the optical axis of the camera lens, the image of the horizontal bands will appear curved. This is also true for any plane above or below the center of the view. The curvature is minimal for the bands when the charge is properly oriented and corrections are not required. An alignment fixture was constructed to allow proper alignment. The fixture has a horizontal scratch mark in front and back which can be aligned with the crosshair inside the camera. The stands were marked in pencil for the alignment of the mirrors and the test sample.

In the orientation of the image, care must be taken in properly aligning the direction of the detonation (as seen on the film) in the same direction as the image sweep speed (fig. 6). If this is not done, the image will be superimposed upon itself because as the detonation moves down the charge, the image sweep will bring the image up over the previously exposed film. When properly aligned, the image sweep will expand the image on the film. A prism image rotator was used to orient the detonation wave to the image sweep speed and to facilatate the final alignment of the images rotation without moving the charge.

The film results for the central initiation of TNT is shown in figure 7 and for the 1/4-inch off-center initiation in figure 8.

ANALYSIS OF FILM RESULTS

The analysis of the detonation wave form is long and tedious, requiring many repetitive calculations, using many data points, and a least-mean square technique. For this reason, a HP-86 personal computer interfaced with a Vanguard motion analyzer was used. A computer listing and flow charts of the program are included in the appendix. The following is a description of the analysis methods used.

By viewing the detonation with mirrors, three views of the charge are obtained: the front, right, and left sides. This allows analysis on almost 360 degrees around the explosive since the edges of the views are difficult to resolve.

The streak picture must be analyzed in order to obtain the position on the film in degrees and time. The position of each measurement is easily obtained by understanding that the projection of the cylinder upon the plane is equal to the radius times the sine of the angle. The scales must be properly applied to the problem in order to obtain the correct angle. The easiest method to calculate the angle is to use the diameter measured directly on the film. In determining the time at each point along a plane, the scaling factors between the film image, the image sweep rate, the precision analyzer, and the event must be known. Computation of the angles in the reflected view require adjustments to match the central view, (90 degrees on the left view and 270 degrees on the right view) and for the shift in directions (clockwise rotation on the charge appears as a counter clockwise rotation in the reflected images).

When measuring the position on points too close to the edge of a view, the measurements cannot be used. A small error in the measurement of the projection will yield a greater error in the computation of the angle measurement along the edges. The section near the rear of the charge (at 180 degrees) cannot be accurately measured because of the reduced resolution on the edges of each view. All other edges are covered in separate views.

Initially, a planar least-mean square analysis is computed on the bands using the positions as they appear on the film, then scaled using the conversion factors to a time in microseconds, not taking into account the change in positions due to the different heights of the film bands. The analysis is made by using multiple regression, determining the time at the bands by minimizing the sum of the squares between the actual and calculated values of time. The equations are readily available for three cartesian coordinates. For this reason the cylindrical measurements of angle are converted into the cartesion coordinate system. The normal equations for two independent variables are:

$$t = n*bo + b1(\sum y) + b2(\sum x)$$

$$xy = bo(\sum y) + b1(\sum y \hat{} 2) + b2(\sum xv) \text{ and}$$

$$xt = bo(\sum x) + b1(\sum xy) + b2(\sum x \hat{} 2)$$

for the planar equation

$$t = bo + b1x + b2y$$

where

t = time

x = the x coordinate

y = the y coordinate

bo,b1,b2 = the constants of the planar equation

Once the planar, least-mean square analysis is obtained, a correction can be made for the height of each individual band. This is done by subtracting the height intercept from the height of the individual band, measured directly on the film, and scaled to microseconds. This correction will yield a correct planar equation in microseconds for each band. In the analysis, the scale on the diameter is not significant because any consistant scale will yield the same tilt. For convenience, the dimensions were not scaled but were left in the Vanguard motion analyzer's dimensions. In the computations, the time zero for the bands need only to be consistant for all of the bands. Only the times between the bands and the points on a individual band are necessary. For this reason, the upper section of the film is used for the zero point to allow a repetitive analysis if necessary. This plane is not used in any other portion of the computations because of the poor resolution obtained along this plane where the detonation wave is spreading out into the main charge from the smaller booster pellet.

The tests are being used to determine the wave tilt and orientation of the tilt. The wave tilt is defined as the angle the intersection of the detonation wave front with the charge perimeter would make with the intersection of a normal detonation (fig 9). The orientation is the angle between the leading edge of the detonation and the zero angle, which faces the camera in the central view. The film results directly yield only the arrival time of the detonation wave front around the perimeter of the charge within distinct planes and not the wave form at a distinct point in time. For this reason, assumptions must be made about the wave form in order to determine the wave tilt. It is assumed that the detonation wave form expands spherically at a constant rate into the nonreacted charge. The intersection between the spherical detonation wave front and the perimeter of the explosive charge will be an ellipse which lies in a plane. It is also assumed that the apparent vertical detonation velocity can be approximated as remaining constant between planes.

The analysis assumes the detonation velocity can be accurately measured vertically down the perimeter of the charge. This is an approximation since the detonation wave is expanding spherically into the charge and may be excessively tilted. For spherical expansion, this approximation is valid for the test sample geometries where the curvature of the detonation wave front is not changing rapidly. This occurs when a detonation wave front is allowed to travel down the charge, expanding considerably before measurement begins, to where the curvature is not changing rapidly. This occurs in charges with a large length-to-diameter ratio.

For the centrally initiated test, it is possible to calculate the apparent detonation velocity along the perimeter of the charge at the film bands (fig. 10). By using the geometry of the test charge, the following ratios of apparent detonation velocity to detonation velocity can be determined:

Band number	Apparent detonation velocity to detonation velocity
1	1.483
2	1.252
3	1.148
4	1.089

The tilt of the detonation wave front can be approximated for large wave tilts by using the apparent detonation velocity. This is true, because the apparent local detonation velocity is measured on the charge where it is used to compute the wave tilt.

The equations for the times the perimeter of the detonation wave front passes each band are obtained in three dimensions: time, x, and y cordinates. The equations will be transformed into two dimensional planar equations by using the coordinates of time and the cosine of the angle to determine the orientation of the wave tilt. The coordinates are rotated so that the side view of the plane will appear as a straight line. This will directly yield the orientation of the tilt from the rotation required to obtain a straight line.

The tilt of the detonation wave front is obtained from the height difference at the leading and trailing edges of the perimeter of the wave front and the charge diameter. The height difference is calculated from the time required for the perimeter of the detonation wave front to cross a plane and the local detonation velocity. The local detonation velocity is obtained from the known band separation divided by the time difference between the intercepts of the time equations for the perimeter of the detonation wave front. The intercept represents the average time for the detonation wave to pass each band.

RESULTS

The time-position graph for the centrally initiated tests (fig. 11) shows the least-mean square curve for each band, as well as the measured times for each band. The data were corrected for the offset caused by the different heights of the film-wrap bands. The graph shows the small variation in time along each band, as well as the close relationship to the measured points and verifies the least-mean square technique used. The height-position graph (fig. 12) shows a plot of the calculation detonation wave plane at the times that half of the detonation wave has passed each band. This shows the position of the detonation wave around the perimeter of the charge as it is calculated from the least-mean square technique.

The polar graph of the tilt rotation of the detonation wave planes (fig. 13) shows the close grouping of the data and the random variation of the rotation of the planar wave tilt. This could be expected from the variations within the charge.

The computer printout of the test results for the centrally initiated test shows a planar wave. The maximum wave tilt was only 1.85 degrees with a minimum of 1.07 degrees. The detonation wave was first recorded on the bands between 157.2 and 120.2 degrees. This indicates that the detonation wave tilt rotated as it travelled down the charge. The rotation was probably due to the internal density variations within the charge.

A test was conducted with the initiation set off center in order to prove the validity of the analysis routine. The booster was offset 1/4-inch along 90 degrees from the center, positioned to the left as viewed by the camera. In an ideal charge, the detonation wave should first reach each band at 90 degrees. The printout shows that the detonation wave initially reaches the bands at a point greater than 90 degrees, up to 16 degrees greater. The range between the rotations was only 4.8 degrees. The consistency of this measurement indicates that the rotation was slightly larger than 90 degrees. This could be due to a large variation in density within the pellet; the detonation velocity decreases with density.

The time-position graph for the 1/4-inch off-center initiation (fig. 14) shows a greater variance between the least-mean square curve and the measured times. This was due to the large variation along each band. The time bands for the off-center initiation are at later times than for the centrally initiated case because of the larger distances the detonation wave travels at an angle through the charge. The position-angle graph (fig. 15) shows the plot of the calculated detonation wave at the time that half of the detonation wave passed each band.

The polar graph of the tilt rotation of the detonation wave front (fig. 16) shows the reducing wave tilt with a rotation of few changes. In an off-center initiation, the wave tilt can be expected to decrease as it travels down the charge; the longer the distance, the more time the detonation wave front has to become more planar. The rotation of the off-center initiation remains in the same range with little random variation. The off-center initiation effects the orientation to a much larger degree than normal internal variations within a charge.

The wave-tilt position graph (fig. 17) compares the wave tilts of the two test runs and shows the large variation between central and off-center initiation.

CONCLUSIONS

The inverse multiprofile streak technique was implemented by ARDEC to make a new measurement technique available to researchers. The method was used with on-center and off-center initiated explosive charges, confirming the viability of the test and analysis methods used. A computer program was developed to simplfy the analysis and allow the use of a larger number of data points. This increases the quality of the results and reduces the change of computation errors in the analysis. The Vanguard motion analyzer was interfaced to a personal computer, allowing direct measurements on the test film to be used in the analysis. The inverse multiprofile streak technique is a valuable new tool in the study of detonation phenomena.

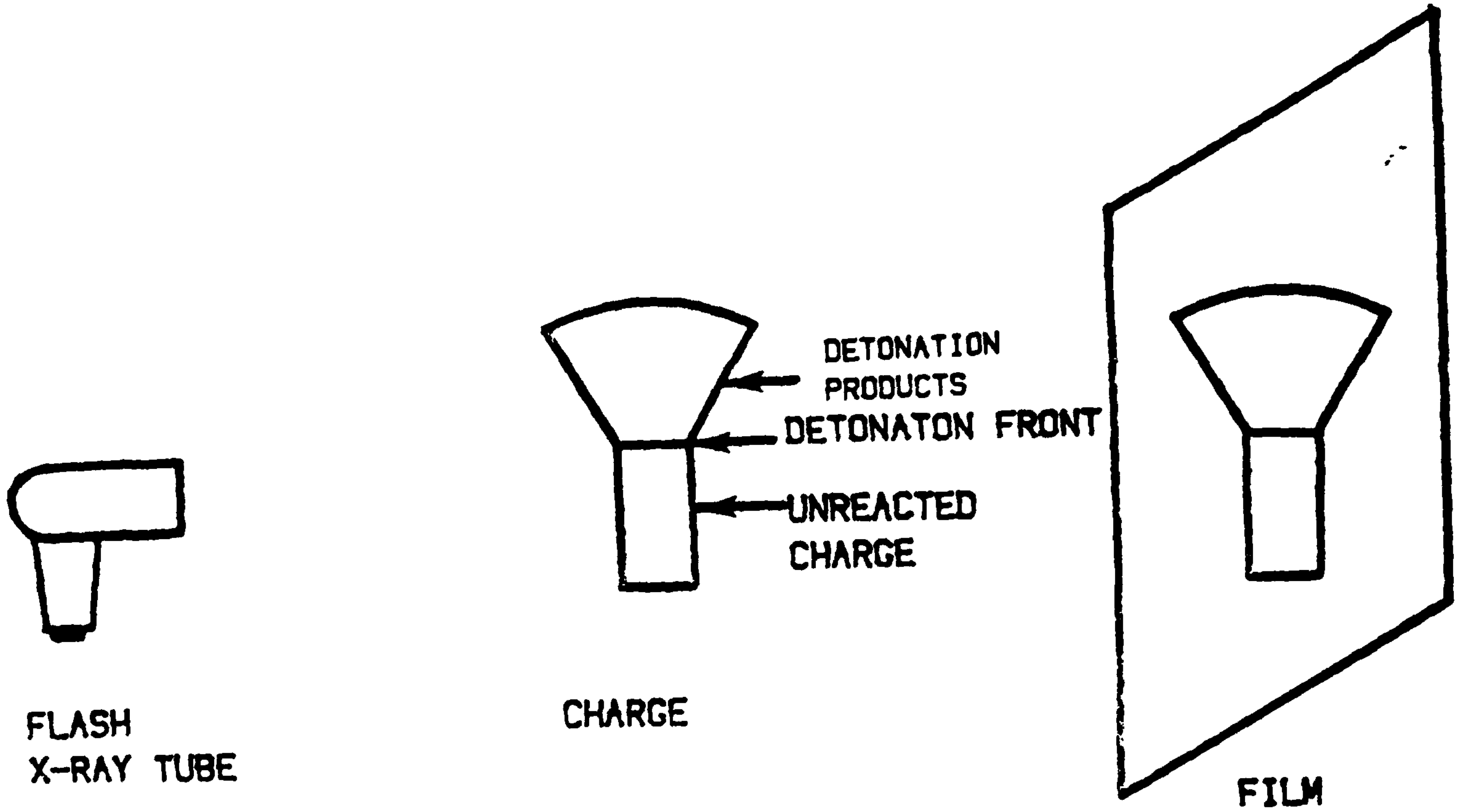


Figure 1. Flash x-ray technique

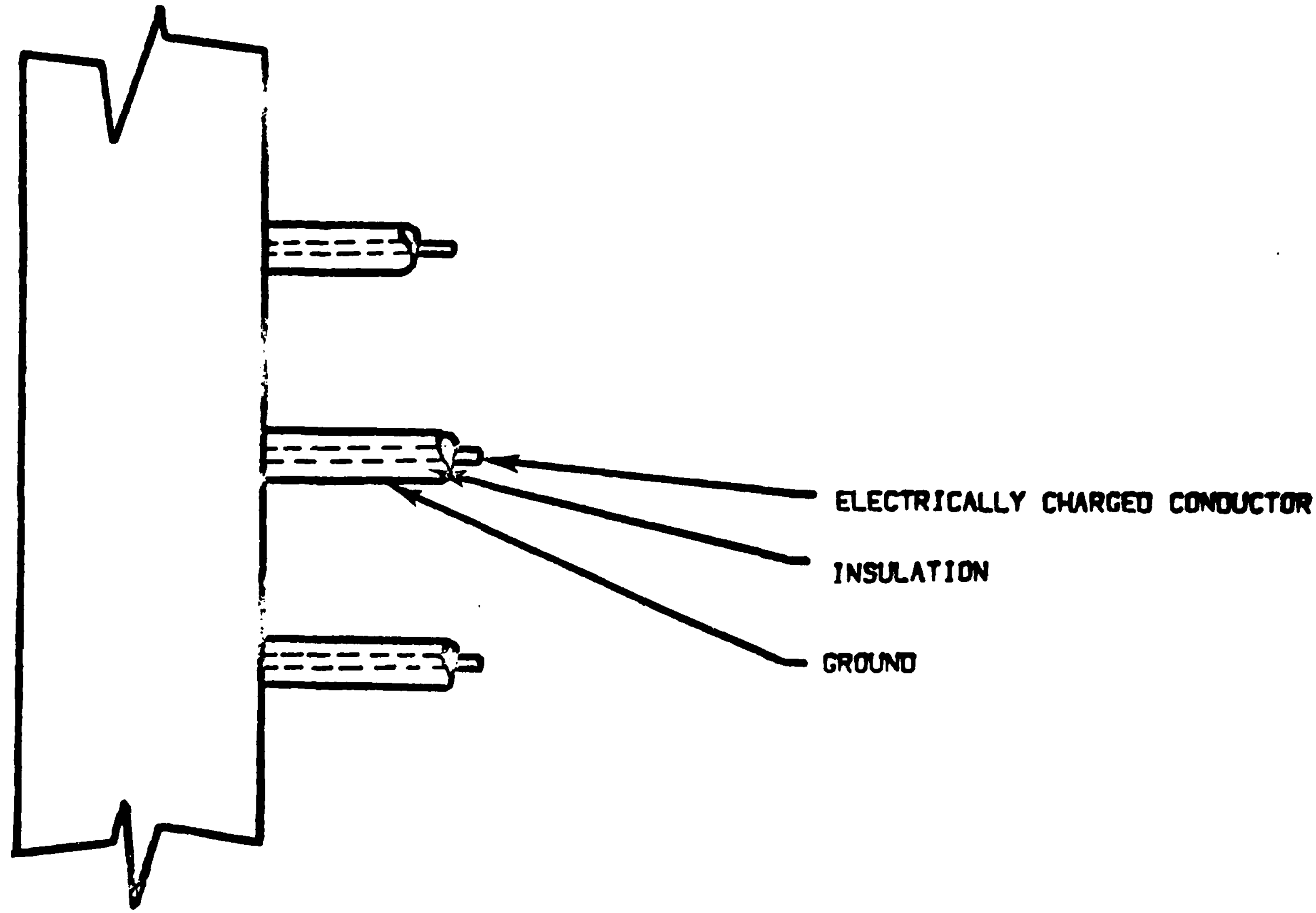


Figure 2. Ionization pin test

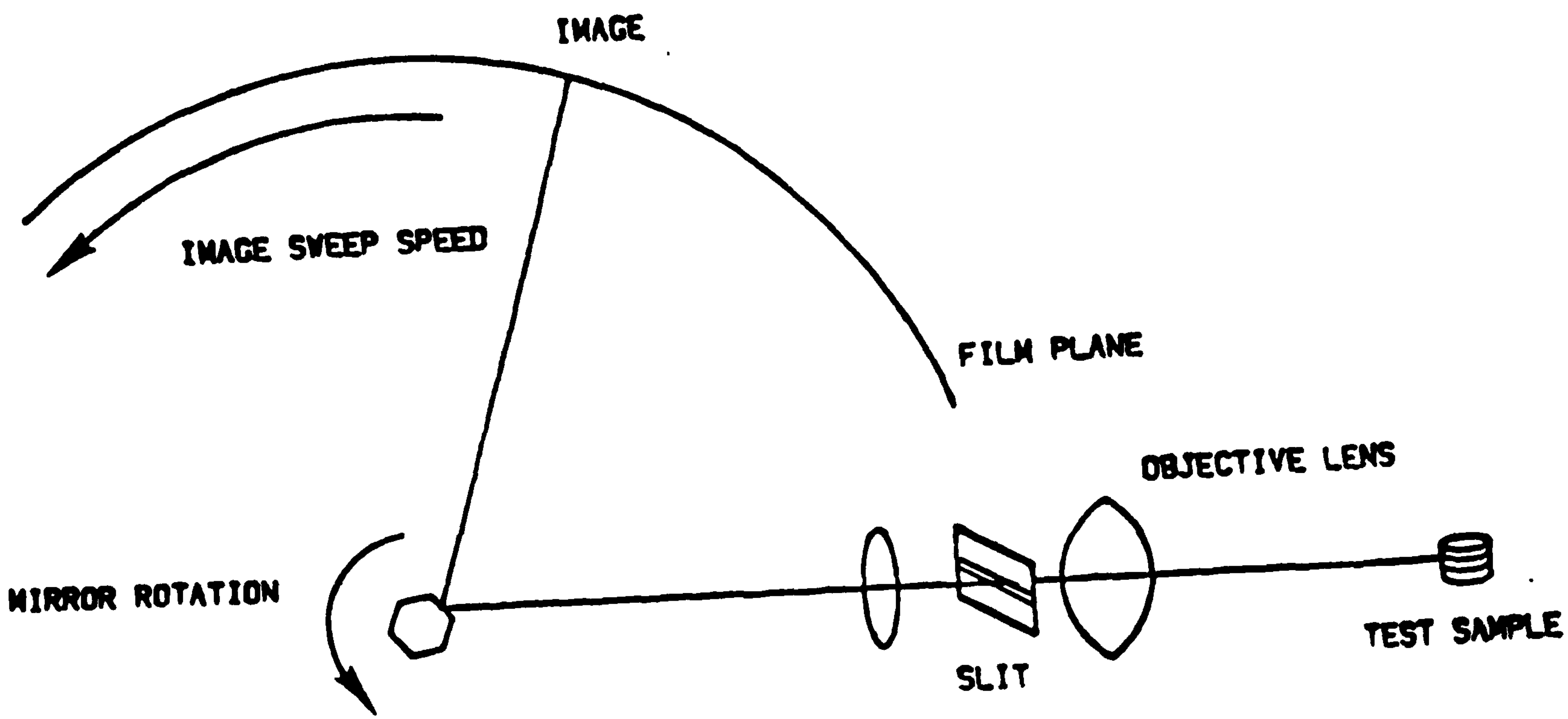


Figure 3. Rotating mirror streak camers

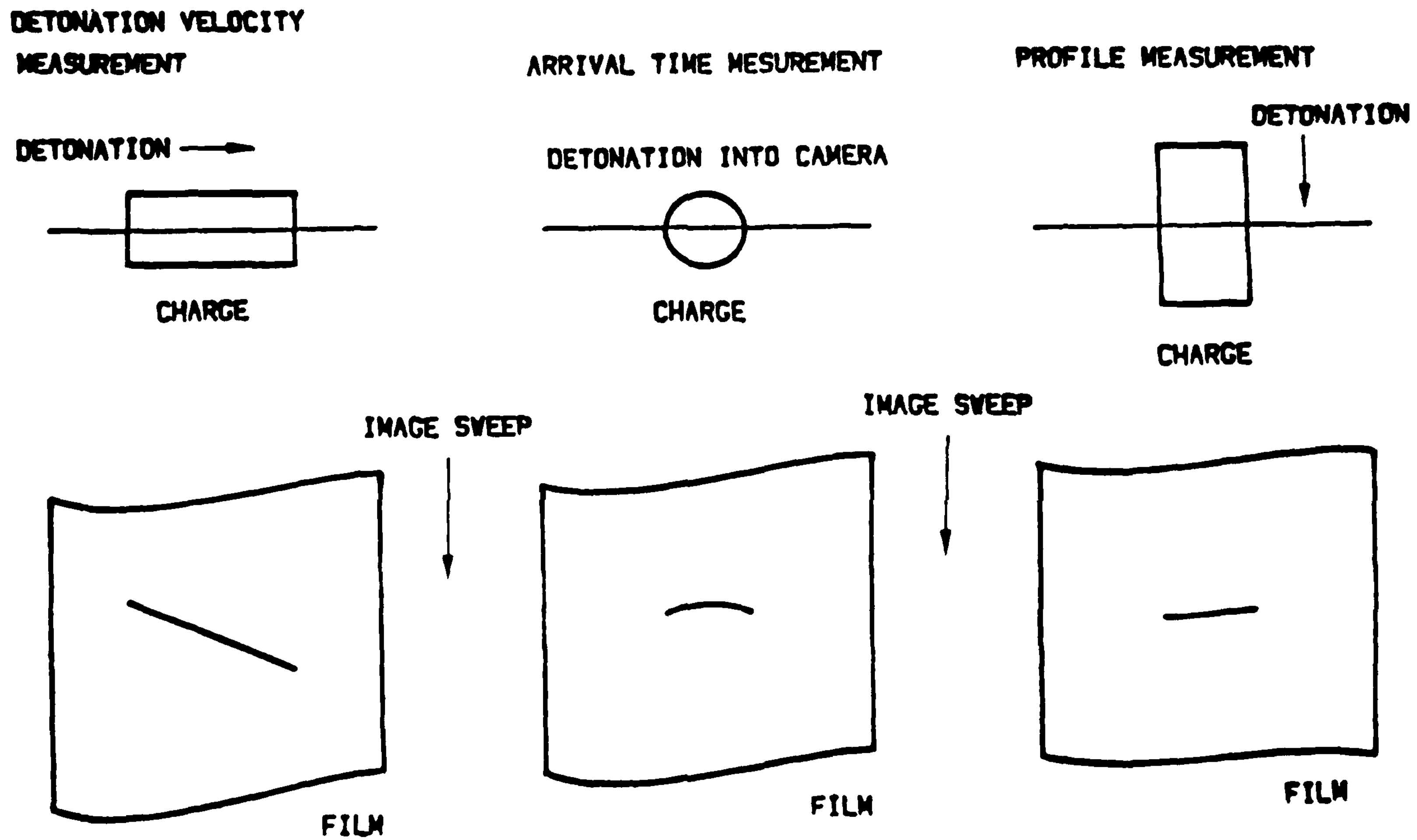


Figure 4. Streak photographic test technique

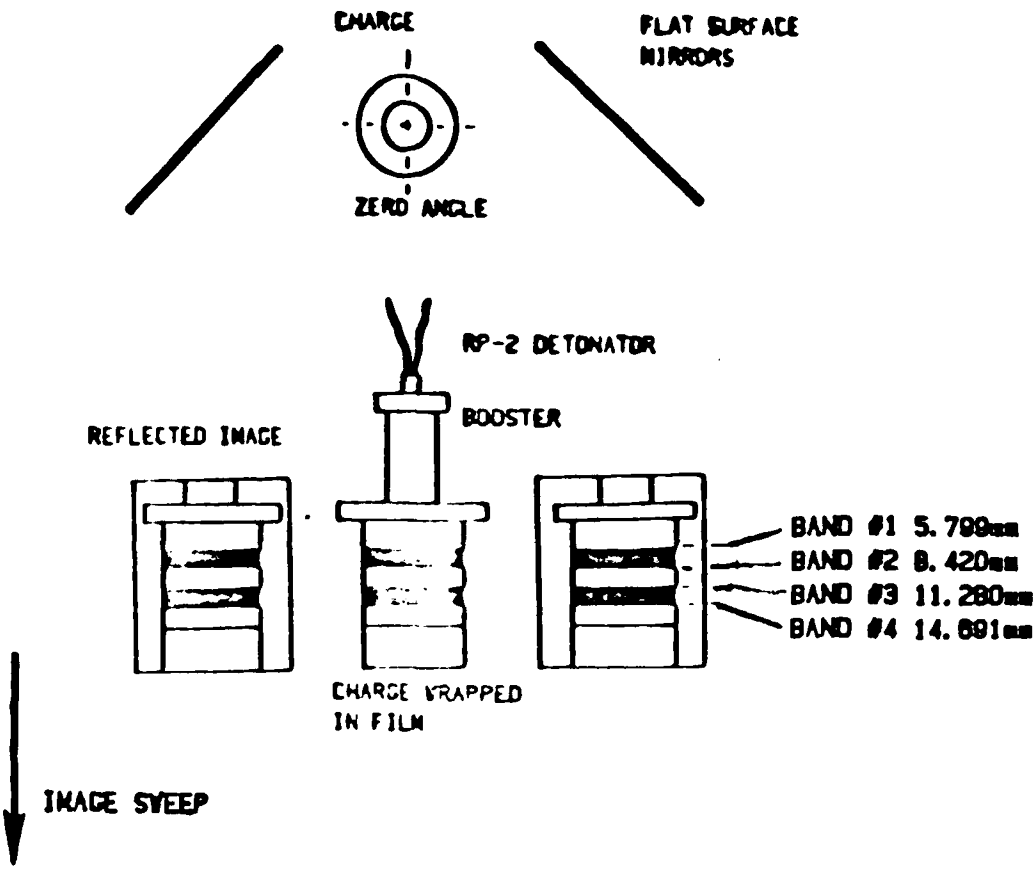


Figure 5. Geometry of the multistreak technique

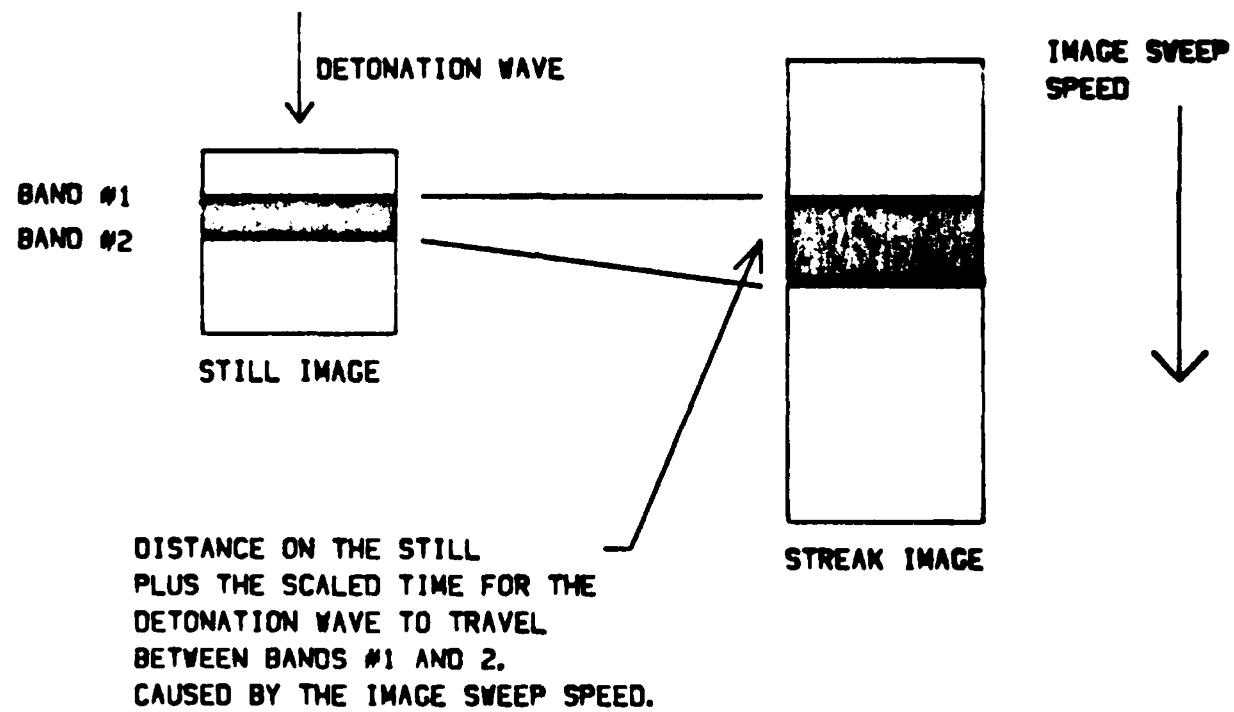


Figure 6. Expansion of image on streak record

Figure 7. Streak picture for the central initiation

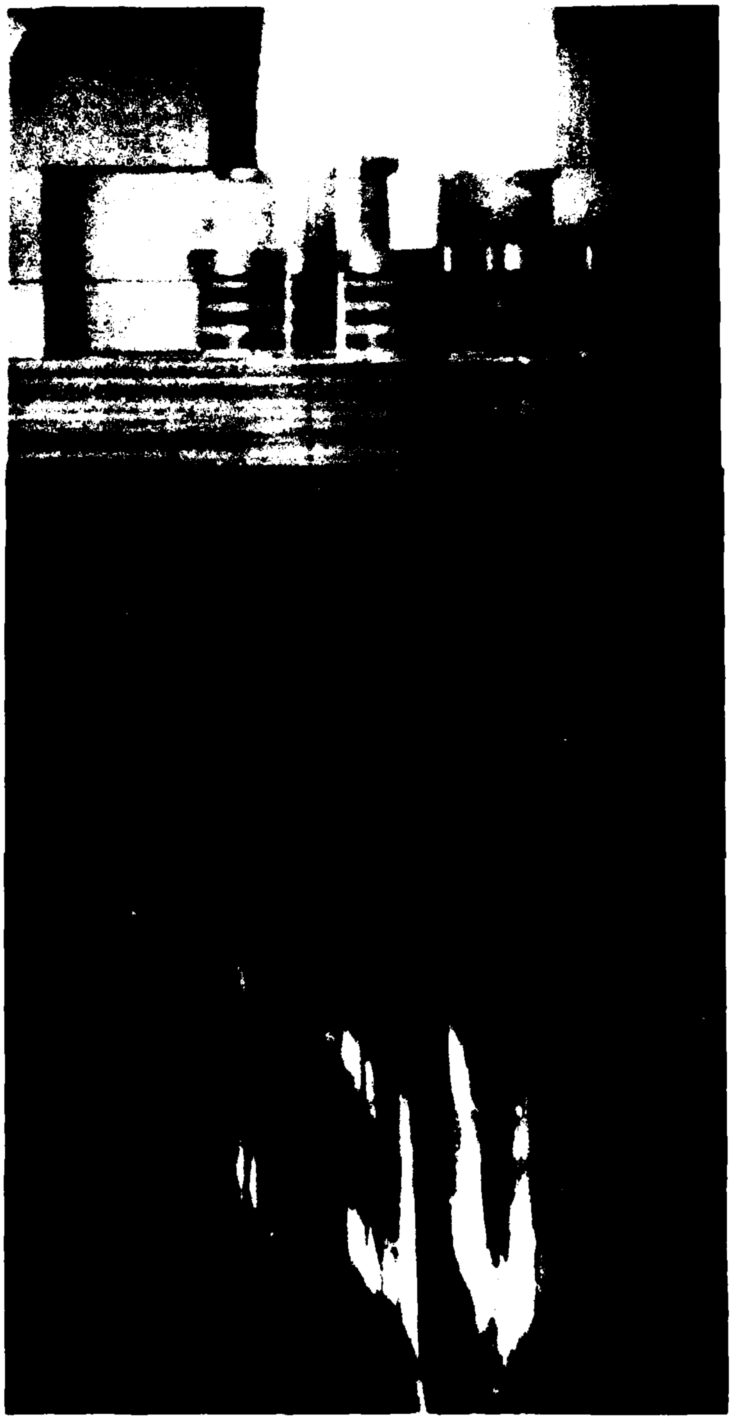


Figure 8. Streak picture for the 1/4-inch off-center initiation

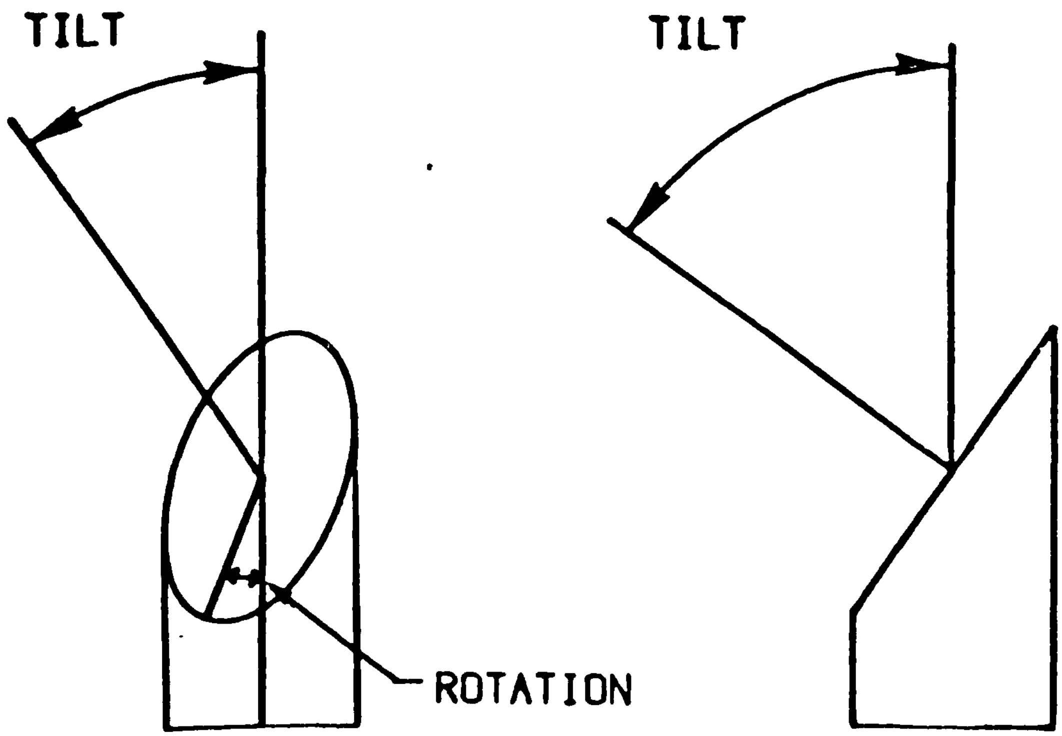
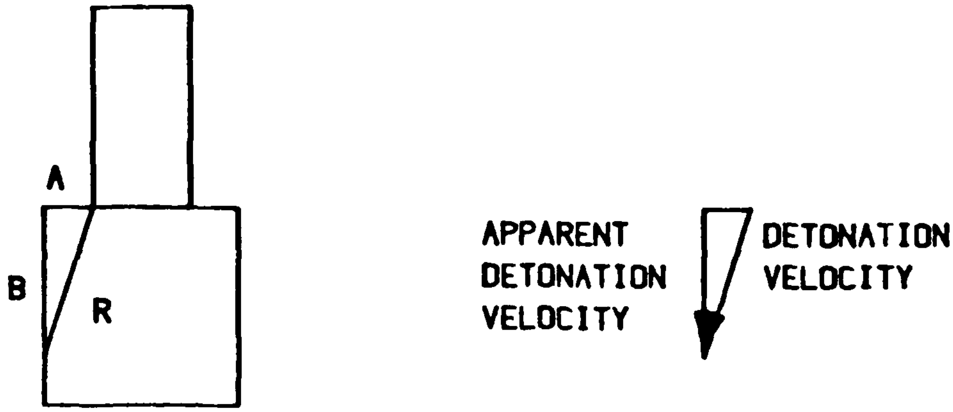


Figure 9. Intersection between detonation wave front and cylinder



$$R^2 = B^2 + A^2$$

$$2R\frac{dR}{dT} = 2B\frac{dB}{dT} + 0$$

$$\frac{dB}{dT} = \frac{R}{B}\frac{dR}{dT}$$

Where:
dR/dT= the detonation velocity
dA/dT=0, unchanging geometry
dB/dT= the apparent detonation velocity

Figure 10. Apparent detonation velocity

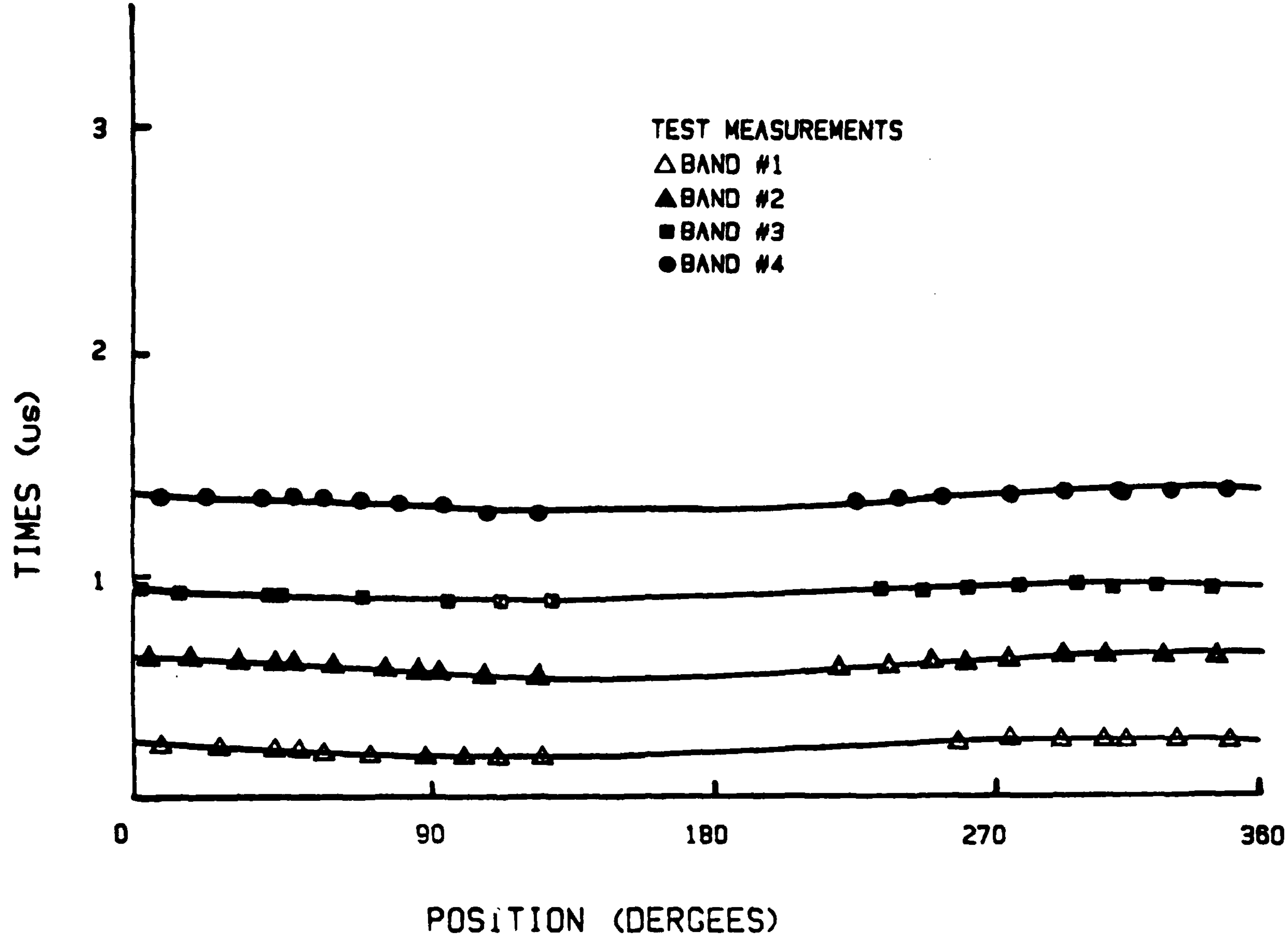


Figure 11. Planar least-mean square times, central initiation

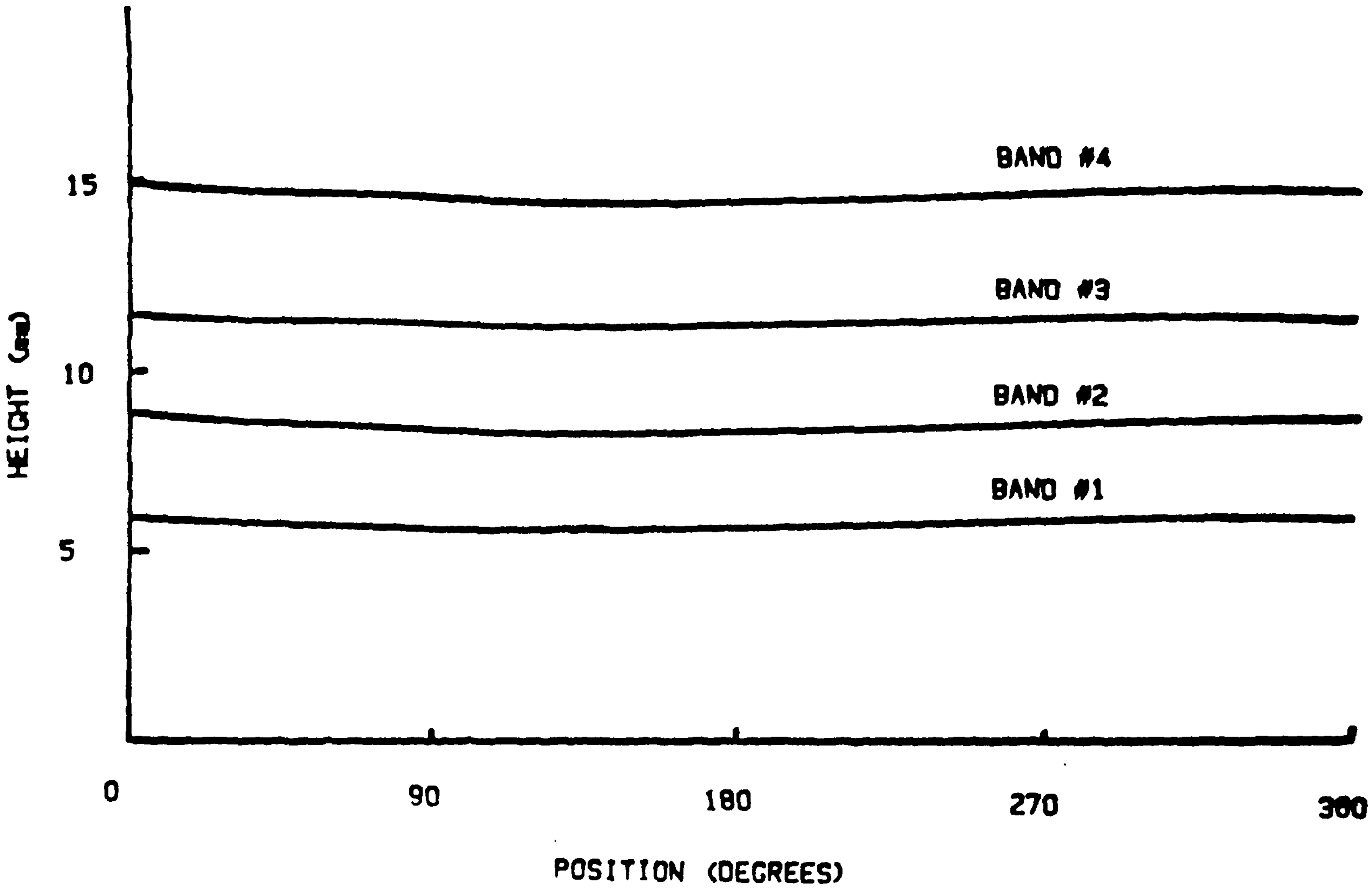


Figure 12. Position of wave form, central initiation

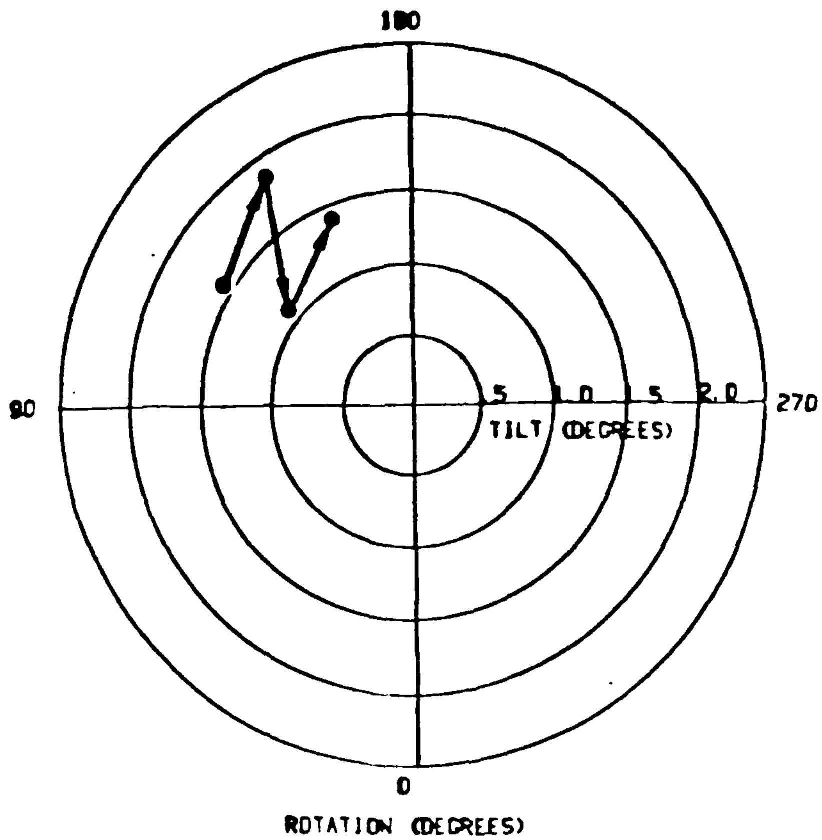


Figure 13. Wave tilt and rotation, central initiation

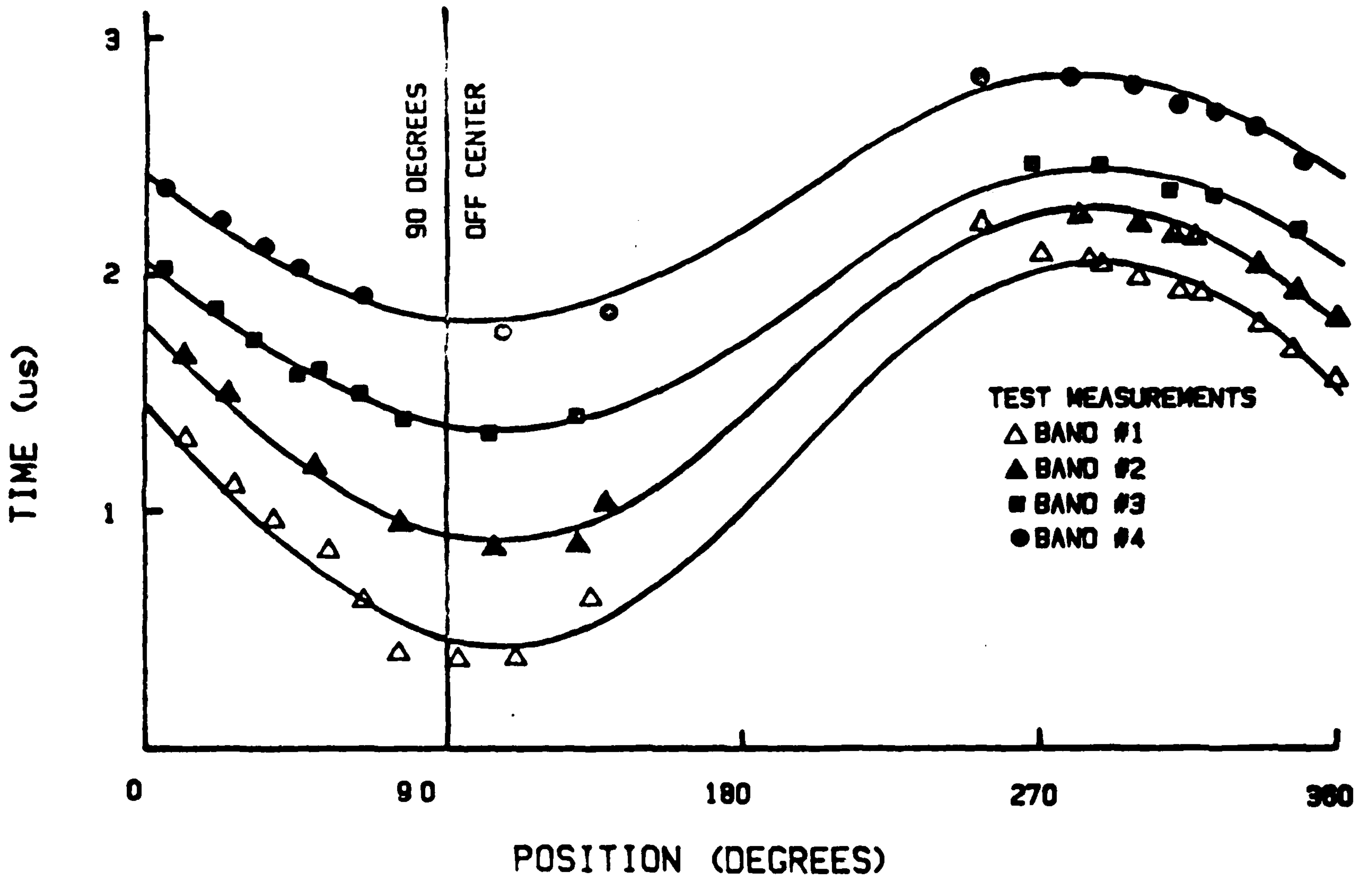


Figure 14. Planar least-mean squar times, 1/4-inch off-center initiation

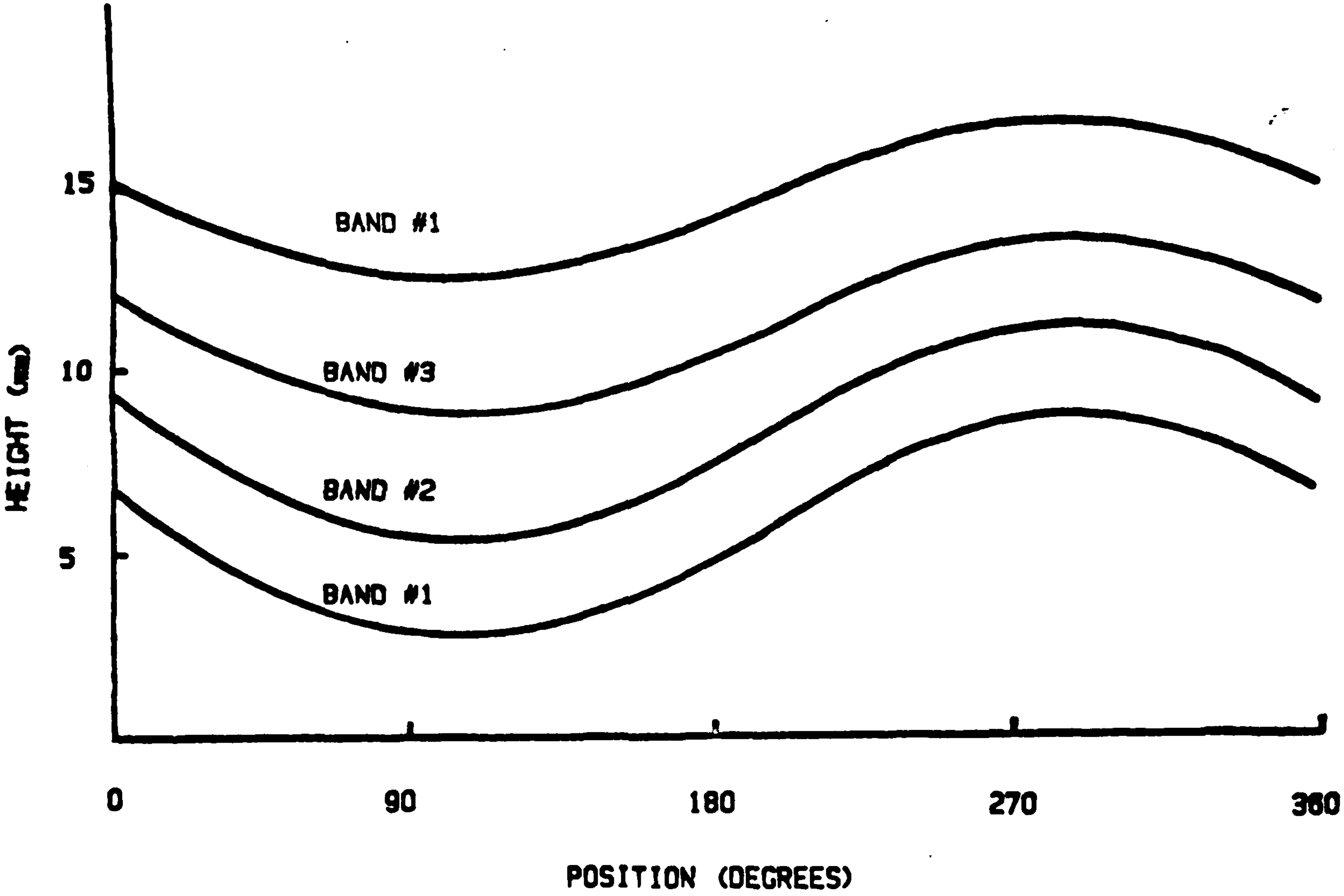


Figure 15. Position of wave form, 1/4-inch off-center initiation

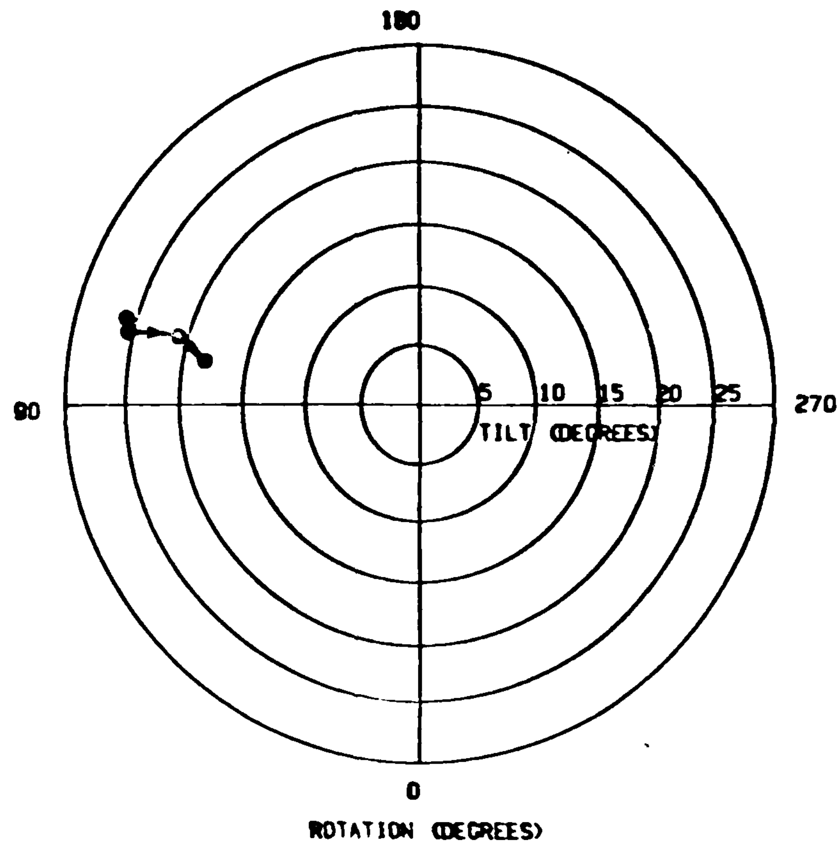


Figure 16. Detonation wave tilts and rotation,
1/4-inch off-center initiation

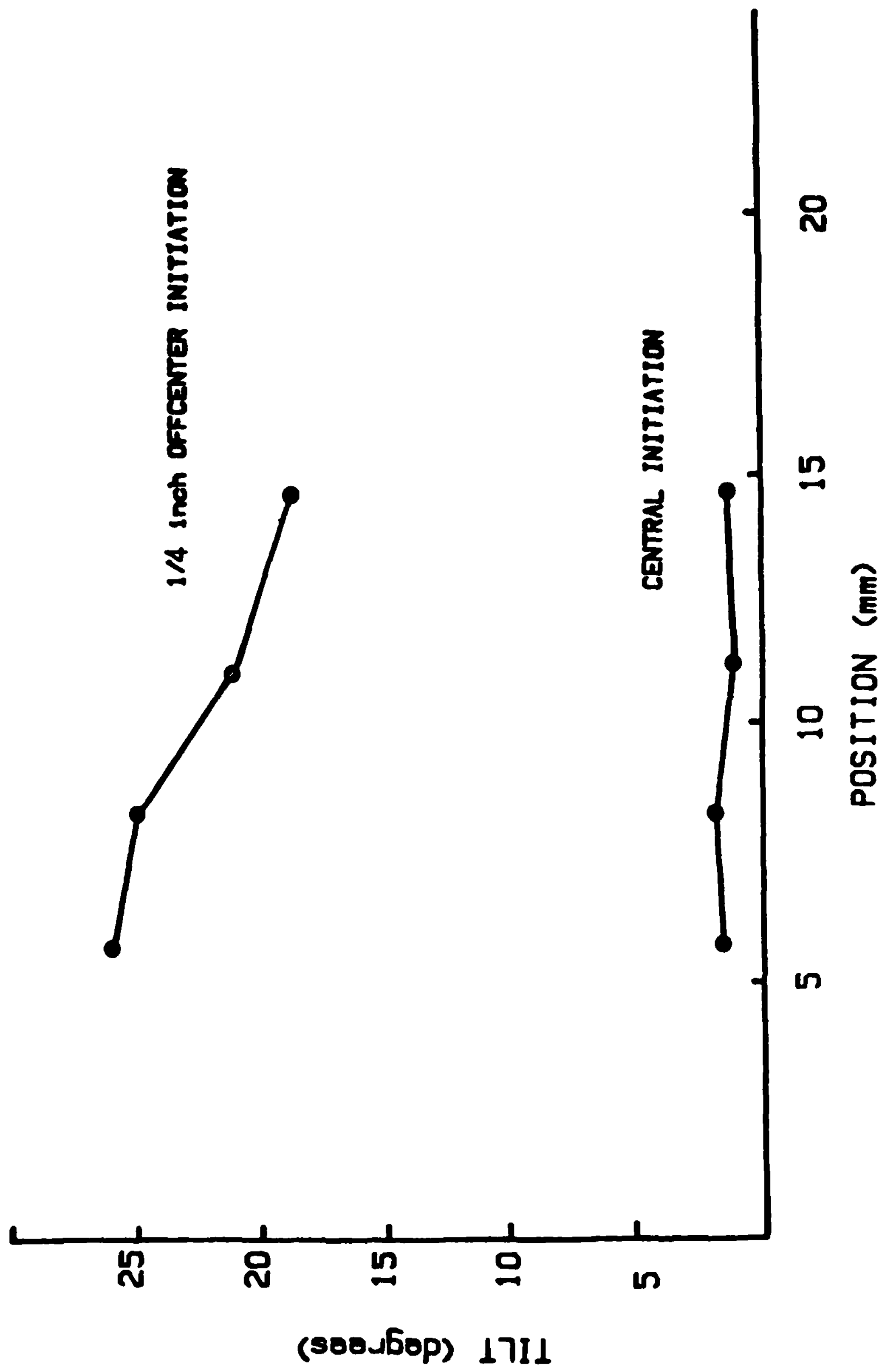


Figure 17. Wave tilts

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2. Jamet, Francis, "Measurements of Densities in Shaped Charge Jets and Detonation Waves," Proceedings of the Flash Radiography Symposium, The American Society of Nondestructive Testing, Houston, Texas, 26 September 1976.

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4. "TNT," Encyclopedia of Explosives and Related Items, vol 9, 1980, p T260.

APPENDIX

PERSONAL COMPUTER PROGRAM

PROGRAM LISTING

```
10  REM MAIN ROUTINE FOR DETERMINING WAVE TILT ON 1" DIA. CHARGE
20  GOSUB RETRIVAL
30  DISP "DATA HAS BEEN RETRIEVED"
40  REM RETRIEVES DATA FROM VANGARD MOTION ANALYZER
50  GOSUB SCALES
60  REM DETERMINES THE SCALE USED LATER IN THE PROGRAM
70  GOSUB VIEWS
80  REM DETERMINES THE ANGLES AND HEIGHTS OF THE BANDS PHOTOGRAPHED
90  REM FROM THE THREE VIEWS MEASURED
100 GOSUB LMS
110 REM DETERMINES THE LEAST MEAN SQUARE TILT OF THE WAVE
120 GOSUB ANGLES
130 REM DETERMINES THE ANGLE OF TILT AND ITS ORIENTATION
140 END
150 REM ****************************************************************
160 RETRIEVAL:
170 REM ****************************************************************
180 REM ** RETRIEVAL SUBROUTINE OBTAINS DATA FROM THE MOTION
    ANALYZER
190 MO=1
200 N=0
210 REM COUNTS THE TOTAL NUMBER OF READINGS TAKEN FOR LATER USE
220 PAGESIZE 24
230 REM INCREASES DISPLAY TO ALLOW 24 LINES TO BE DISPLAYED
240 CLEAR
250 REM CLEAR DISPLAY
260 PRINTER IS 501
270 REM SELECTS ADDRESS CODE TO THE PRINTER, 5-- GPIB, 01 PRINTER
280 DIM H(200),X(200),Y(200),TH(4,200),X1(4,200)
290 DIM BO(4),B1(4),B2(4),AL(4),DL(4)
300 REM DIMENSIONS VARIABLES USED IN PROGRAM
310 REM H,HEADER X,X DIRCTION Y,Y DIRECTION TH,ANGLE X1, HEIGHT
320 REM TI, TILT ANGLE, BO,B1,B2,AL,DL, PLANAR COEFFICIENTS
330 DISP " THE FIRST DIAL ON THE HEADER MUST BE SET TO A NON-ZERO
    NUMBER"
340 DISP "UNTIL THE LAST READING, ZERO SIGNALS THAT THE DATA ACQUISION"
```

```
350 DISP "HAS BEEN COMPLETED" 360
360 DISP "SET THE POSITIVE DIRECTIONS ON THE VANGARD MOTION
    ANALYZER"
370 DISP "RIGHT AND UPWARDS ARE THE POSITIVE DIRECTION"
380 REM
390 DISP "NEXT INSERT THE STILL FILM SUCH THAT THE EMULSION IS FACING
    UP"
400 DISP "AND TOP OF DETONATION TO THE RIGHT"
410 REM SETS THE SIDE OF THE FILM BEING MEASURED
420 DISP "ZERO THE SMALL MOTION ANALYZER ALONG THE BASE AND CENTRAL
    VIEW"
430 REM ALLOWS FOR CHECKING THE DATA AT A LATER POINT
440 DISP "ENTER THE FILM SPEED IN R.P.S."
450 INPUT U
460 U=U/250 ! mm/µs
470 PRINT "FILM SPEED ";U;" mm/µS"
480 REM ENTERS FILM SPEED IN R.P.S. WHICH IS THEN CONVERTED TO mm/µS
490 REM OF IMAGE SWEEP RATE ACROSS THE FILM
500 DISP ""
510 DISP ""
520 DISP ""
530 DISP ""
540 DISP ""
550 DISP "INPUT THE DATA IN THE FOLLOWING FORMAT"
560 DISP "READINGS 1 & 2 THE SCALE OF 4 FILM DIVISIONS (SPROCKETS)"
570 "                FROM LEFT TO RIGHT"
580 DISP "READINGS 3 & 4 THE SIZE OF THE CENTER VIEW FROM TOP TO
    BOTTOM"
590 DISP "READINGS 5 & 6 THE SIZE OF THE TOP VIEW FROM TOP TO BOTTOM"
600 DISP "READINGS 7 & 8 THE SIZE OF THE BOTTOM VIEW FROM TOP TO
    BOTTOM"
610 DISP "READINGS 9 & 10 THE SCALE OF THE BANDS ON THE PICTURE"
620 DISP "FROM RIGHT TO LEFT"
630 DISP ""
640 DISP "INSERT STREAK RECORD EMULSION FACE UP, DETONATOR TO
    THE RIGHT"
```

```
650  DISP "ZERO ON THE CENTRAL AXIS OF THE CENTRAL VIEW ALONG THE"
660  DISP "RIGHT HAND SIDE"
670  REM INSURES THE STREAK AND STILL RECORD ARE READ FROM THE SAME SIDE
680  IF MO=1 THEN 830
690  DISP ""
700  DISP "ENTER THE STREAK BANDS USING THE HEADER IN THE FOLLOWING
     MANNER"
710  REM THE HEADER IS A THUMB WHEEL USED BY THE OPERATOR TO IDENTIFY
720  REM THE READING BEING TAKEN
730  DISP "ENTER DATA FROM TOP TO BOTTOM AND RIGHT TO LEFT"
740  DISP "THE VERTICAL BANDS ARE NUMBERED FROM ONE TO THREE,"
750  DISP "BAND NUMBER ONE IS ON THE FAR RIGHT"
760  DISP ""
770  DISP "THE VIEWS ARE NUMBERED FROM ONE TO THREE, VIEW ONE ON TOP,"
780  DISP "VIEW TWO IN THE CENTER, AND VIEW THREE ON THE BOTTOM"
790  DISP "THE HEADER MUST BE SET APPROPRIATELY FOR EACH READING"
800  DISP "THE VIEW IS SET ON HEADER DIAL #4 AND THE BAND ON
     DIAL # 5
810  MO=0 @ GOTO 880
820  REM MO IS USED TO ROUTE THE PROGRAM THROUGH THE INSTRUCTIONS
830  Z(1)=5.799
840  Z(2)=8.4201
850  Z(3)=11.28
860  Z(4)=14.691
870  REM ACTUAL SIZE OF BANDS MEASURED IN mm
880  PRINT
890  PRINT
900  PRINT "HEADER      ", "X DIRECTION","Y DIRECTION"
910  PRINT
920  DISP
930  DISP
940  DISP "HEADER       ", "X DIRECTION","Y DIRECTION"
950  DISP
960  REM TITLES THE DATA APPEARING ON THE SCREEN AND PRINTER
     SEPARATELY
```

```
970  ENTER 10 USING "#,8A,3X,7A,X,7A,3X"; H$,X$,Y$
980  N=N+1
990   REM INCREMENTS N
1000  REM ENTERS DATA OVER RS-32
1010  REM #, NO CARRIAGE RETURN 8A, 8 DIGIT STRING, 3X, THREE SPACES NO
      ENTRY
1020  REM 7A, 7 DIGIT STRING, X ONE SPACE, 7A, 7 DIGIT STRING,
      3X, THREE SPACES
1030  REM H$,X$, & Y$ ARE STRING CHARACTERS THAT ARE IN INVERSE VIDEO
1040  REM, NUMBERS ON A LIGHT BACKGROUND AND CANNOT BE USED IN MATH
      FUNCTIONS
1050  FOR J=1 TO 8 ! 8 DIGIT STRING
1060      H1$[J,J]=CHR$ (NUM (H$[J,J])-128)
1070  NEXT J
1080  H(N)=VAL (H1$)
1090  REM CONVERTS H1$ INTO A NUMBER VARIABLE
1100  REM -128 IS THE ASC-2 OFFSET FOR THE INVERSE TO NUMERIC VARIABLE
      SHIFT
1110  REM VAL FUNCTION CONVERTS NUMBERS IN STRING INTO NUMERIC VARIABLES
1120  REM AND SETS H INTO MATRIX
1130  FOR J=1 TO 7 ! 7 DIGIT STRING
1140     X1$[J,J]=CHR$ (NUM (X$[J,J])-128)
1150     Y1$[J,J]=CHR$ (NUM (Y$[J,J])-128)
1160  NEXT J
1170  X(N)=VAL (X1$)
1180  Y(N)=VAL (Y1$) ! REM VANGARD DIVISIONS
1190  REM CONVERTS X & Y STRING VARIABLES INTO NUMERIC VARIABLES
1200  REM AND SETS X & Y INTO MATRIX
1210  DISP H(N);"  ","  ";X(N),"  ";Y(N)
1220  PRINT H(N);"  ","  ";X(N),"  ";Y(N)
1230  IF N=10 THEN MO=2
1240  REM SETS MO TO 2 AFTER INITIALIZING DATA IS OBTAINED
1250  IF MO=2 THEN 680
1260  REM ROUTES PROGRAM AFTER OBTAINING SCALES
1270  A=NUM (H1$)
1280  IF A=48 THEN RETURN
```

```
1290 REM RETURNS TO MAIN PROGRAM IF THE FIRST DIGIT IN THE HEADER
     EQUALS ZERO
1300 REM SIGNIFYING THE DATA ACQUISITION IS FINISHED
1310 REM ASC-2 CODE OF 48 IS EQUIVALENT TO ZERO
1320 GOTO 970
1330 REM ***************************************************************
1340 SCALES:
1350 REM ***************************************************************
1360 REM SCALES SUBROUTINE DETERMINES THE SCALE FUNCTIONS REQUIRED
1370 REM IN DETERMINING THE TILT
1380 SC=ABS (4*4.75/(X(1)-X(2))) ! UNITS mm ON FILM / VANGARD
     DIVISION
1390 REM THERE ARE 4.75 mm BETWEEN SPROCKETS ON THE FILM
1400 REM ALLOWS THE SCALING OF FILM SPEED FROM THE VANGARD
     MEASUREMENTS
1410 PRINT "SC= ";SC;"mm ON FILM / VANGARD DIVISION"
1420 DIA=ABS (Y(3)-Y(4)) ! VANGARD DIVISIONS
1430 REM MEASURED DIA OF CENTRAL VIW ON FILM IN VANGARD DIVISIONS
1440 R=DIA/2
1450 REM RADIUS OF CENTRAL VIEW
1460 S=(X(9)-X(10))/8.892*SC
1470 REM S IS THE SCALE OF mm ON FILM / mm ACTUAL
1480 REM 8.892 IS THE ACTUAL SIZE OF THE BANDS IN mm
1490 REM S IS DETERMINED FROM THE VERITICAL SCALE ON THE BANDS
1500 PRINT "S= ";S'"mm ON FILM/mm ACTUAL"
1510 RETURN
1520 REM ***************************************************************
1530 VIEWS:
1540 REM ***************************************************************
1550 REM THIS SUBROUTINE DETERMINES THE ANGLES OF EACH READING
1560 REM AND SETS UP A TWO DIMENSIONAL MATRIX USING BANDS AND
1570 REM THE COUNT ON THE BAND TO DEFINE THE ANGLES AND HEIGHTS
1580 REM OF EACH READING
1590 E1=0
1600 E2=0
1610 E3=0
```

```
1620  E4=0
1630  REM E1 THROUGH E4 ARE THE COUNTS ON THE INDIVIDUAL BANDS
1640  N=N-1
1650  REM LAST READING LEAVES THE DATA ACQUISITION ONLY, NO DATA
1660  FOR J=11 TO N
1670  REM FIRST 10 READINGS WERE FOR SCALING
1680  B$=VAL$ (H(J))
1690  REM PUT HEADER INTO STRING VARIABLE B$
1700  B=VAL (B$[5,5])
1710  REM PLACES 5TH NUMBER IN B$ INTO VARIABLE B
1720  REM WHICH IS THE BAND NUMBER
1730  IF B=1 THEN E1=E1+1 @ E=E1
1740  IF B=2 THEN E2=E2+1 @ E=E2
1750  IF B=3 THEN E3=E3+1 @ E=E3
1760  IF B=4 THEN E4=E4+1 @ E=E4
1770  REM DETERMINES COUNTS ON EACH BAND AND PLACES COUNT INTO TEMPORARY
      VARIABLE
1780  REM VARIABLE E
1790  V=VAL (B$[4,4])
1800  REM DETERMINES THE 4TH VARIABLE IN THE HEADER, THE VIEW NUMBER
1810  IF V=1 THEN VO=(Y(5)+Y(6)/2 @ G=PI / 2 @ YA=-1
1820  IF V=2 THEN VO=(Y(3)+Y(4))/2 @ G=0 @ YA=1
1830  IF V=3 THEN VO=(Y(7)+Y(8))/2 @ G=3*PI / 2 @ YA=-1
1840  REM ANGLE IS DETERMINED FOR EACH VIEW FROM ITS CENTER
1850  REM THEN THE REFLECTED VIEWS ARE ROTATED TO THE CENTRAL
1860  REM VIEWS ZERO ANGLE, THROUGH G
1870  REM THE MIRROR IMAGES ARE REVERSED SO YA IS USED TO
1880  REM CORRECT THE ANGLES, YA=-1 FOR REFLECTED VIEWS
1890  TH(B,E)=ASN (YA*(Y(J)-VO)/R)+G
1900  REM DETERMINES THE ANGLE FROM THE CENTER OF THE CENTRAL VIEW
1910  REM AND PLACES IT INTO THE MATRIX
1920  REM NOTE THE DIMENSIONS ARE IN VANGARD DIVISIONS
1930  IF TH(B,E)<0 THEN TH(B,E)=TH(B,E)+2*PI
1940  REM ANGLES ARE ROTATED UNTIL THE EQUIVALENT POSITIVE ANGLE IS
      OBTAINED
1950  X1(B,E)=X(J)
```

```
1960 REM PLACES HEIGHT INTO MATRIX
1970 PRINTO "THETA (";B;E;")= ";TH(B,E)*360/(2*PI )
1980 PRINT "    AT THE HEIGHT ";X1(B,E)
1990 NEXT J
2000 RETURN
2010 REM ***************************************************************
2020 LMS:
2030 REM ***************************************************************
2040 FOR B=1 TO 4
2050 IF B=1 THEN E=E1
2060 IF B=2 THEN E=E2
2070 IF B=3 THEN E=E3
2080 IF B=4 THEN E=E4
2090 REM COUNT ON INDIVIDUAL BAND IS PUT INTO E
2100 BM=0 @ CM=0 @ FM=0 @ ET=0 @ H2=0 @ AM=0 @ GM=0 @ DM=0
2110 REM INITIALIZING VARIABLES REUSED FOR EACH BAND
2120 FOR J=1 TO E
2130    REM LEAST MEAN SQUARE ON EACH BAND
2140    YL=R*SIN (TH(B,J))
2150    XL=R*COS (TH(B,J))
2160    ZL=X1(B,J)*(SC/U)*(-1)
2170    REM SCALE SC/U CONERTS X1 INTO THE TIME SCALE, "B
2180    BM=BM+YL
2190    CM=CM+XL
2200    BM=FM+YL*XL
2210    ET=ET+YL>2
2220    H2=H2+XL>2
2230    AM=AM+ZL
2240    GM=GM+XL*ZL
2250    DM=DM+YL*ZL
2260 NEXT J
2270 REM DETERMINES THE VARIABLES NEEDED TO DETERMINE A LEAST MEAN
2280 REM SQUARE PLANE
2290 L1+(AM/E-GM/CM)/(BM/E-FM/CM)
2300 L2=GM*BM/CM-DM
2310 L3=BM*FM/CM-ET
```

```
2320  L4=FM-H2*BM/CM
2330  L5=(H2/CM-CM/E)/(BM/E-FM/CM)
2340  B2(B)=(L2/L3-L1)/(L5-L4/L3)
2350  REM B2 IS A COEFFICIENT OF PLANAR EQUATION
2360  REM L*'S ARE USED ONLY TO SPLIT THE LONG EQUATIONS USED
2370  REM L VARIABLES WILL BE REUSED WHEN NEEDED
2380  L1=DM-BM*GM/CM
2390  L2=BM*H2/CM-FM
2400  B1(B)-(L1+L2*B2(B))/L3
2410  REM NOTE L3 IS THE SAME VARIABLE USED BEFORE
2420  L1=AM/BM-DM/ET+B2(B)*(FM/ET-CM/BM)
2430  L2=E/BM-BM/ET
2440  B0(B)-L1/L2
2450  REM THE COEFFICIENTS B0,B1,B2 FOR THE PLANER EQUATION
2460  REM HAVE NOW BEEN DETERMINED FOR THE PRESENT BAND ON THE
2470  REM PRESENT COUNT
2480  REM THE EQUATION IS OF THE FORM
2490  REM T=B0+B1*Y+B2*X
2500  REM NOTE THE DIMENSIONS ARE AGAIN IN VANGARD DIVISIONS
2510  REM SINCE THE BANDS ARE INITIALLY SEPARATED THE TIME PLANE
2520  REM MUST BE CORRECTED FOR THE INTERCEPT, B0
2530  REM THE METHOD FOR DOING THIS IS TO SUBTRACTED THE SCALED
2540  REM HEIGHT OF THE BAND AT THIS POINT
2550  B0(B)=B0(B)-Z(B)*(S/U)
2560  REM S/U IS THE SCALE FACTOR TO CONVERT mm ACTUAL TO μs
2570  PRINT "AT BAND NUMBER ";B;" THE PLANAR EQUATION IS "
2580  PRINT "TIME= ";B0(B);" + ";B1(B);" *Y+ ";B2(B);" *X"
2590  NEXT B
2600 RETURN
2610  REM ***************************************************************
2620  ANGLES:
2630  REM ***************************************************************
2640  REM THE PROBLEM NOW IS TO FIND THE ANGLE BETWEEN THE PLANE
2650  REM AND THE FORM PLANE, TIME =B0
2660  FOR B=1 TO 4
2670     DL(B)=ATN (B1(B)/B2(B))
```

```
2680     AL(B)=-(R*B2(B)/COS (DL(B)))
2690     REM A COORDINATE TRANSFER IS REQUIRED TO CYLINDRICAL
         COORDINATES
2700     REM THE FORM OF THE INTERSECTION OF THE PLANAR EQUATION
         DESIRED
2710     REM IS TIME=BO+AL*COS(TH+DL), WHERE DL IS THE ANGLE OF
         ROTATION
2720     REM TO REDUCE THE SIN TERM OF THE TRANSFORMATION TO ZERO
2730     REM THE ABOVE EQUATIONS ARE THE CONSTANTS FOR THE
         TRANSFORMATION
2740     REM NOTE THE DIMENSIONS ARE IN VANGARD DIVISIONS
2750     PRINT "ZERO ANGLE FOR BAND ";B'"IS ";DL(B)*360/(2*PI);"
         DEGREES"
2760     PRINT "AT BAND ";B
2770     PRINT "TIME= ";BO(B);"+";AL(B);"COS(TH+ ";DL(B)*360/
         (2*PI );")"
2780  NEXT B
2790  PRINT " "
2800  REM PRINTS A BLANK LINE
2820  TI(1)=ATN ((Z(2)-Z(1))/(BO(2)-BO(1))*(AL(1)*2)/25.4)
2830  PRINT ""
2840  PRINT "TILT ONE = ";TI(1)*360/(2*PI );" DEGREES"
2850  PRINT "   AT A ROTATION OF ";DL(1)*360/(2*PI );" DEGREES"
2860  TI(2)=ATN ((Z(3)-Z(1))/(BO(3)-BO(1))*(AL(2)*2)/25.4)
2870  PRINT ""
2880  PRINT "TILT TWO = ";TI(2)*360/(2*PI );" DEGREES"
2890  PRINT "   AT A ROTATION OF ";DL(2)*360/(2*PI );" DEGREES"
2900  TI(3)=ATN ((Z(4)-Z(2))/(BO(4)-BO(2))*(AL(3)*2)/25.4)
2910  PRINT ""
2920  PRINT "TILT THREE = ";TI(3)*360/(2*I );" DEGREES"
2930  PRINT "   AT A ROTATION OF ";DL(3)*360/(2*PI );" DEGREES"
2940  TI(4)=ATN ((Z(4)-Z(3))/(BO(4)-BO(3))*(AL(4)*2)/25.4)
2950  PRINT ""
2960  PRINT "TILT FOUR = ";TI(4)*360/(2*PI );" DEGREES"
2970  PRINT "   AT A ROTATION OF ";DL(4)*360/(2*PI );"DEGREES"
2980  REM THIS SEGMENT CALCULATE THE WAVE TILT USING THE
```

```
2990 REM TIME RELATIONSHIPS ALREADY CALCULATED
3000 REM THE LOCAL DETONATION VELOCITY IS CALCULATED BY COMPUTING
3010 REM THE TIME THE CENTER OF THE WAVE CROSSES THE BAND
3020 REM PLANES (THE CHANGE IN HEIGHT,Z,DIVIDED BY THE
3030 REM CHANGE IN TIME, BO).
3040 REM THE TIME IT TAKES THE WAVE TO PASS AN INDIVIDUAL
3050 REM BAND PLANE IS ALSO NEEDED, 2*AL.  THE FACT IS
3060 REM MULTIPLIED BY 2 TO OBTAIN THE FULL TIME SINCE
3070 REM THE TIME EQUATION, TIME = BO+AL*COS(TH+DL)
3080 REM IS LINEAR IN THE TIME AND COS(TB+DL) COORDINATES.
3090 REM GOING FROM COS(0)+COS(180) IS EQUAL TO 1+1 OR TWO
3100 REM THE WAVE TILT IS THEN CALCULATED FROM THE
3110 REM DETONATION VELOCITY AND THE TIME REQUIRED TO PASS
3120 REM A PLANE IS THEN USED TO CALCULATE THE WAVE TILT.
3130 REM THE ROTATION OF THE WAVE WAS CALCULATED EARLIER.
3140 BEEP @ BEEP @ BEEP
3150 RETURN
```

COMPUTER PRINTOUT FOR CENTRAL INITIATION

FILM SPEED 5.872 mm/μs

HEADER	X DIRECTION	Y DIRECTION
10000000	-3.264	0
10000000	-.136	0
10000000	0	.324
10000000	0	-.324
10000000	0	1.171
10000000	0	.525
10000000	0	-.569
10000000	0	-1.213
10000000	.481	-1.213
10000000	.28	-1.213

HEADER	X DIRECTION	Y DIRECTION
10011000	-.325	1.054
10011000	-.311	1.009
10011000	-.303	.93
10011000	-.303	.841
10011000	-.291	.76
10011000	-.29	.642
10021000	-.326	.229
10021000	-.338	.151
10021000	-.346	.052
10021000	-.359	-.054
10021000	-.361	-.148
10021000	-.358	-.226
10031000	-.362	-.851
10031000	-.384	-.944
10031000	-.373	-1.033
10031000	-.374	-1.094

10032000	-.78	-1.094
10032000	-.805	-1.037
10032000	-.783	-.938
10032000	-.771	-.864
10032000	-.756	-.798
10032000	-.738	-.714
10032000	-.747	-.658
10022000	-.795	-.248
10022000	-.804	-.166
10022000	-.8	-.083
10022000	-.793	.017
10022000	-.781	.095
10022000	-.768	.172
10022000	-.768	.23
10012000	-.715	.646
10012000	-.709	.739
10012000	-.708	.806
10012000	-.713	.856
10012000	-.724	.912
10012000	-.735	1.002
10012000	-.759	1.06
10012000	-.759	1.06
10013000	-1.15	1.064
10013000	-1.144	.944
10013000	-1.105	.79
10013000	-1.097	.702
10013000	-1.092	.633
10023000	-1.131	.222
10023000	-1.146	.092
10023000	-1.14	.012
10023000	-1.136	-.09
10023000	-1.149	-.172
10023000	-1.162	-.238
10033000	-1.145	-.719
10033000	-1.15	-.79
10033000	-1.168	-.869

10033000	-1.167	-.964
10033000	-1.172	-1.063
10033000	-1.157	-1.111
10034000	-1.648	-1.111
10034000	-1.646	-1.034
10034000	-1.644	-.951
10034000	-1.635	-.822
10034000	-1.627	-.741
10034000	-1.615	-.687
10024000	-1.635	-.23
10024000	-1.643	-.154
10024000	-1.644	-.07
10024000	-1.641	.037
10024000	-1.65	.124
10024000	-1.635	.212
10014000	-1.566	.645
10014000	-1.57	.734
10014000	-1.592	.808
10014000	-1.613	.884
10014000	-1.626	.948
10014000	-1.646	1.016
10014000	-1.65	1.058
0	-1.65	1.058

SC = 6.0741 mm on film/vangard divisions

S = .1373 mm on film/mm actual

THETA (1, 1) = 50.5204
AT THE HEIGHT -.325

THETA (1, 2) = 60.2039
AT THE HEIGHT -.311

THETA (1, 3) = 75.3397
AT THE HEIGHT -.303

THETA (1, 4) = 91.2379
AT THE HEIGHT -.303

THETA (1, 5) = 105.7597
AT THE HEIGHT -.291

THETA (1, 6) = 129.4795
AT THE HEIGHT -.29

THETA (1, 7) = 44.9743
AT THE HEIGHT .326

THETA (1, 8) = 27.7781
AT THE HEIGHT .338

THETA (1, 9) = 9.2355
AT THE HEIGHT -.346

THETA (1, 10) = 350.4059
AT THE HEIGHT -.359

THETA (1, 11) = 332.8198
AT THE HEIGHT -.361

THETA (1, 12) = 315.7707
AT THE HEIGHT -.358

THETA (1, 13) = 262.9083
AT THE HEIGHT -.362

THETA (1, 14) = 279.4147
AT THE HEIGHT -.384

THETA (1, 15) = 295.9936
AT THE HEIGHT -.373

THETA (1, 16) = 308.7955
AT THE HEIGHT -.374

THETA (2, 1) = 308.7955
AT THE HEIGHT -.78

THETA (2, 2) = 296.7832
AT THE HEIGHT -.805

THETA (2, 3) = 278.3408
AT THE HEIGHT -.783

THETA (2, 4) = 265.2198
AT THE HEIGHT -.771

THETA (2, 5) = 253.3193
AT THE HEIGHT -.756

THETA (2, 6) = 236.886
AT THE HEIGHT —.738

THETA (2, 7) = 224.0168
AT THE HEIGHT -.747

THETA (2, 8) = 310.0545
AT THE HEIGHT -.795

THETA (2, 9) = 329.1797
AT THE HEIGHT -.804

THETA (2, 10) = 345.1569
AT THE HEIGHT -.8

THETA (2, 11) = 3.0076
AT THE HEIGHT -.793

THETA (2, 12) = 17.0502

AT THE HEIGHT -.781

THETA (2, 13) = 32.0638

AT THE HEIGHT -.768

THETA (2, 14) = 45.2248

AT THE HEIGHT -.768

THETA (2, 15) = 128.560

AT THE HEIGHT -.715

THETA (2, 16) = 109.6588

AT THE HEIGHT -.709

THETA (2, 17) = 97.4481

AT THE HEIGHT -.708

THETA (2, 18) = 88.5851

AT THE HEIGHT -.713

THETA (2, 19) = 78.6073

AT THE HEIGHT -.724

THETA (2, 20) = 61.6205

AT THE HEIGHT -.735

THETA (2, 21) = 49.1318

AT THE HEIGHT -.759

THETA (3, 1) = 48.1896

AT THE HEIGHT -1.15

THETA (3, 2) = 72.7647

AT THE HEIGHT -1.144

THETA (3, 3) = 100.3122
AT THE HEIGHT -1.105

THETA (3, 4) = 116.7832
AT THE HEIGHT -1.097

THETA (3, 5) = 131.5734
AT THE HEIGHT -1.092

THETA (3, 6) = 43.2501
AT THE HEIGHT -1.131

THETA (3, 7) = 16.4961
AT THE HEIGHT -1.146

THETA (3, 8) = 2.1225
AT THE HEIGHT -1.114

THETA (3, 9) = 343.8723
AT THE HEIGHT -1.136

THETA (3, 10) = 327.9361
AT THE HEIGHT -1.149

THETA (3, 11) = 312.7292
AT THE HEIGHT -1.162

THETA (3, 12) = 237.9361
AT THE HEIGHT -1.145

THETA (3, 13) = 251.8365
AT THE HEIGHT -1.15

THETA (3, 14) = 266.1065
AT THE HEIGHT -1.168

THETA (3, 15) = 283.0210

AT THE HEIGHT -1.167

THETA (3, 16) = 302.0638

AT THE HEIGHT -1.172

THETA (3, 17) = 312.7665

AT THE HEIGHT -1.157

THETA (4, 1) = 312.7665

AT THE HEIGHT -1.648

THETA (4, 2) = 296.1905

AT THE HEIGHT -1.646

THETA (4, 3) = 280.6719

AT THE HEIGHT -1.644

THETA (4, 4) = 257.7039

AT THE HEIGHT -1.635

THETA (4, 5) = 242.4215

AT THE HEIGHT -1.627

THETA (4, 6) = 230.9771

AT THE HEIGHT -1.615

THETA (4, 7) = 314.7751

AT THE HEIGHT -1.635

THETA (4, 8) = 331.6205

AT THE HEIGHT -1.643

THETA (4, 9) = 347.5229

AT THE HEIGHT -1.644

THETA (4, 10) = 6.5573
AT THE HEIGHT -1.641

THETA (4, 11) = 22.5020
AT THE HEIGHT -1.65

THETA (4, 12) = 40.8681
AT THE HEIGHT -1.635

THETA (4, 13) = 128.7955
AT THE HEIGHT -1.566

THETA (4, 14) = 110.6006
AT THE HEIGHT -1.157

THETA (4, 15) = 97.0916
AT THE HEIGHT -1.592

THETA (4, 16) = 83.6206
AT THE HEIGHT -1.613

THETA (4, 17) = 72.0225
AT THE HEIGHT -1.626

THETA (4, 18) = 58.767
AT THE HEIGHT -1.646

THETA (4, 19) = 49.5978
AT THE HEIGHT -1.65

AT BAND NUMBER 1 THE PLANAR EQUATION IS
TIME = .2088 + .1090 *Y+ .0636

AT BAND NUMBER 2 THE PLANAR EQUATION IS
TIME = .5769 + .0884 *Y+ .1361

AT BAND NUMBER 3 THE PLANAR EQUATION IS

TIME = .9098 + .0698 *Y+ .537

AT BAND NUMBER 4 THE PLANAR EQUATION IS

TIME = 1.3301 + .0458 *Y+ .1092

ZERO ANGLE FOR BAND 1 IS 59.7555 DEGREES AT BAND 1

TIME = .2088 + .0409* COS(TH+59.7555)

ZERO ANGLE FOR BAND 2 IS 33.0268 DEGREES AT BAND 2

TIME = .5769 + .0526* COS(TH + 33.0268)

ZERO ANGLE FOR BAND 3 IS 52.4504 DEGREES AT BAND 3

TIME = .9098 + .0285* COS(TH+ 52.4504)

ZERO ANGLE FOR BAND 4 IS 22.7668 DEGREES AT BAND 4

TIME = 1.3301 + .0384* COS(TH+ 22.7668)

TILT ONE = 1.5790 DEGREES

AT A ROTATION OF 120.2444 DEGREES

TILT TWO = 1.859 DEGREES

AT A ROTATION OF 146.9731 DEGREES

TILT THREE = 1.0718 DEGREES

AT A ROTATION OF 127.5495 DEGREES

TILT FOUR = 1.4049 DEGREES

AT A ROTATION OF 157.2331 DEGREES

COMPUTER PRINTOUT FOR 1/4 inch OFFCENTER INITIATION

FILM SPEED 6.336 mm/μs

HEADER	X DIRECTION	Y DIRECTION
10000000	-4.403	-1.131
10000000	-1.257	-1.131
10000000	-1.257	.33
10000000	-1.257	-.33
10000000	-1.257	1.204
10000000	-1.257	.599
10000000	-1.257	-.529
10000000	-1.257	-1.137
10000000	.296	1.137
10000000	0	1.137

HEADER	X DIRECTION	Y DIRECTION
10011000	-1.077	1.091
10011000	-.846	1.033
10011000	-.616	.979
10011000	-.559	.874
10011000	-.58	.781
10011000	-.699	.703
10011000	-.857	.674
10021000	-1.207	.209
10021000	1.367	.147
10021000	-1.581	.07
10021000	-1.794	-.011
10021000	-1.923	-.081
10021000	-2.039	-.14
10021000	-2.207	-.223
10031000	-2.391	-.828
10031000	2.345	-.921

10031000	-2.281	-.993
10031000	-2.21	-1.045
10032000	-2.577	-1.045
10032000	-2.628	-.995
10032000	-2.671	-.899
10032000	-2.672	-.73
10022000	-2.556	-.229
10022000	-2.433	-.146
10022000	-2.314	-.085
10022000	-2.185	-.007
10022000	-2.031	.063
10022000	-1.852	.139
10012000	-1.402	.65
10012000	-1.19	.69
10012000	-1.158	.815
10012000	-1.262	.978
10012000	-1.534	1.106
10013000	-2.032	1.099
10013000	-1.917	1.047
10013000	-1.804	.966
10013000	-1.755	.819
10013000	-1.831	.694
10023000	-2	.239
10023000	-2.153	.184
10023000	-2.33	.121
10023000	-2.527	.027
10023000	-2.527	.027
10023000	-2.666	-.069
10023000	-2.845	-.201
10033000	-2.961	-.817
10033000	-2.952	-.939
10033000	-2.867	-1.043
10034000	-3.362	-1.043
10034000	-3.443	-.982
10034000	-3.485	-.882
10034000	-3.478	-.716

10024000	-3.34	-.209
10024000	-3.257	-.151
10024000	-3.116	-.069
10024000	-2.976	.03
10024000	-2.849	.119
10024000	2.73	.189
10014000	-2.43	.658
10014000	-2.326	.802
10014000	-2.509	1.041
10014000	-2.634	1.133
0	-2.634	1.132

SC = 6.0394 mm on film/vangard divisions

S = .2010 mm on film/mm actual

THETA (1, 1) = 54.9534

AT THE HEIGHT -1.077

THETA (1, 2) = 66.5165

AT THE HEIGHT -.846

THETA (1, 3) = 76.4173

AT THE HEIGHT -.616

THETA (1, 4) = 94.7801

AT THE HEIGHT -.559

THETA (1, 5) = 111.4169

AT THE HEIGHT -.58

THETA (1, 6) = 126.9784

AT THE HEIGHT -.699

THETA (1, 7) = 133.5821

AT THE HEIGHT .857

THETA (1, 8) = 39.2964
AT THE HEIGHT -1.207

THETA (1, 9) = 26.4524
AT THE HEIGHT -1.367

THETA (1, 10) = 12.2466
AT THE HEIGHT -1.581

THETA (1, 11) = 358.0897
AT THE HEIGHT -1.794

THETA (1, 12) = 345.7913
AT THE HEIGHT -1.923

THETA (1, 13) = 334.8972
AT THE HEIGHT -2.039

THETA (1, 14) = 317.4869
AT THE HEIGHT -2.207

THETA (1, 15) = 269.1318
AT THE HEIGHT -2.391

THETA (1, 16) = 285.4660
AT THE HEIGHT -2.345

THETA (1, 17) = 299.0025
AT THE HEIGHT -2.281

THETA (1, 18) = 309.9728
AT THE HEIGHT -2.21

THETA (2, 1) = 309.9728
AT THE HEIGHT -2.577

THETA (2, 2) = 299.4003
AT THE HEIGHT -2.628

THETA (2, 3) = 281.53[illegible]9
AT THE HEIGHT -2.671

THETA (2, 4) = 251.8128
AT THE HEIGHT -2.672

THETA (2, 5) = 316.0572
AT THE HEIGHT -2.556

THETA (2, 6) = 333.7413
AT THE HEIGHT -2.433

THETA (2, 7) = 345.0737
AT THE HEIGHT -2.314

THETA (2, 8) = 358.7845
AT THE HEIGHT -2.185

THETA (2, 9) = 11.0058
AT THE HEIGHT -2.031

THETA (2, 10) = 24.9111
AT THE HEIGHT -1.852

THETA (2, 11) = 139.6515
AT THE HEIGHT -1.402

THETA (2, 12) = 129.8596
AT THE HEIGHT -1.19

THETA (2, 13) = 105.1959
AT THE HEIGHT -1.158

THETA (2, 14) = 76.5958
AT THE HEIGHT -1.262

THETA (2, 15) = 51.7059
AT THE HEIGHT -1.534

THETA (3, 1) = 53.2385
AT THE HEIGHT -2.032

THETA (3, 2) = 63.8381
AT THE HEIGHT -1.917

THETA (3, 3) = 78.7287
AT THE HEIGHT -1.804

THETA (3, 4) = 104.4775
AT THE HEIGHT -1.755

THETA (3, 5) = 128.9607
AT THE HEIGHT -1.831

THETA (3, 6) = 46.4058
AT THE HEIGHT -2

THETA (3, 7) = 33.8883
AT THE HEIGHT -2.153

THETA (3, 8) = 21.5101
AT THE HEIGHT -2.33

THETA (3, 9) = 4.6930
AT THE HEIGHT -2.527

THETA (3, 10) = 347.9309
AT THE HEIGHT -2.666

THETA (3, 11) = 322,4762
AT THE HEIGHT -2.845

THETA (3, 12) = 267.2209
AT THE HEIGHT -2.961

THETA (3, 13) = 288.7362
AT THE HEIGHT -2.952

THETA (3, 14) = 309.5211
AT THE HEIGHT -2.867

THETA (4, 1) = 309.5211
AT THE HEIGHT 3.362

THETA (4, 2) = 396.8409
AT THE HEIGHT -3.443

THETA (4, 3) = 278.5391
AT THE HEIGHT 3.485

THETA (4, 4) = 249.2344
AT THE HEIGHT 3.478

THETA (4, 5) = 320.7035
AT THE HEIGHT -3.34

THETA (4, 6) = 332.7692
AT THE HEIGHT -3.257

THETA (4, 7) = 347.9309
AT THE HEIGHT -3.116

THETA (4, 8) = 5.2159
AT THE HEIGHT -2.976

THETA (4, 9) = 21.1374

AT THE HEIGHT -2.846

THETA (4, 10) = 34.9406

AT THE HEIGHT -2.73

THETA (4, 11) = 137.5510

AT THE HEIGHT -2.43

THETA (4, 12) = 107.5486

AT THE HEIGHT -2.326

THETA (4, 13) = 64.9931

AT THE HEIGHT -2.509

THETA (4, 14) = 45.4513

AT THE HEIGHT -2.634

AT BAND NUMBER 1 THE PLANAR EQUATION IS

TIME = 1.2415 + 2.3746 *Y+ .6858

AT BAND NUMBER 2 THE PLANAR EQUATION IS

TIME = 1.5888 + 2.0897 *Y+ .5543

AT BAND NUMBER 3 THE PLANAR EQUATION IS

TIME = 1.8958 + 1.6766 *Y+ .4716

AT BAND NUMBER 4 THE PLANAR EQUATION IS

TIME = 2.3183 + 1.5808 *Y+ .3173

ZERO ANGLE FOR BAND 1 IS 73.8908 DEGREES AT BAND 1

TIME = 1.2415 + .8156 * COS (TH+73.8908)

ZERO ANGLE FOR BAND 2 IS 75.1444 DEGREES AT BAND 2

TIME = 1.5888 + .7134 * COS (TH + 75.1444)

ZERO ANGLE FOR BAND 3 IS 74.2885 DEGREES AT BAND 3

TIME = 1.8958 + .5747 * COS(TH+ 74.2885)

ZERO ANGLE FOR BAND 4 IS 78.6503 DEGREES AT BAND 4

TIME = 2.3183 + .5320 * COS (TH+ 78.6503)

TILT ONE = 25.8610 DEGREES

AT A ROTATION OF 106.1091 DEGREES

TILT TWO = 25.2008 DEGREES

AT A ROTATION OF 104.8555 DEGREES

TILT THREE = 21.2575 DEGREES

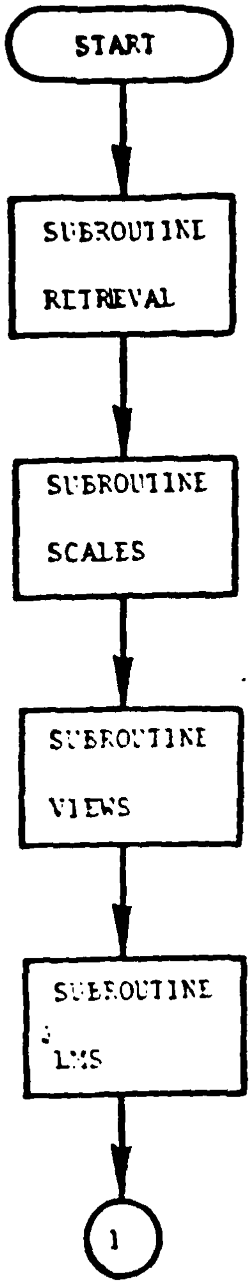
AT A ROTATION OF 105.7114 DEGREES

TILT FOUR = 18.6898 DEGREES

AT A ROTATION OF 101.3496 DEGREES

FLOW CHART

MAIN ROUTINE

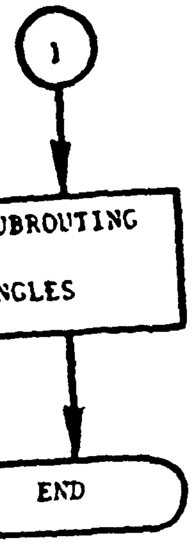


SUBROUTINE RETRIEVAL OBTAINS MEASUREMENTS FROM VANGUARD MOTION ANALYZER

SUBROUTINE SCALES DETERMINES THE SCALES BETWEEN THE FILM, THE VANGUARD MEASUREMENTS, AND THE TEST SETUP

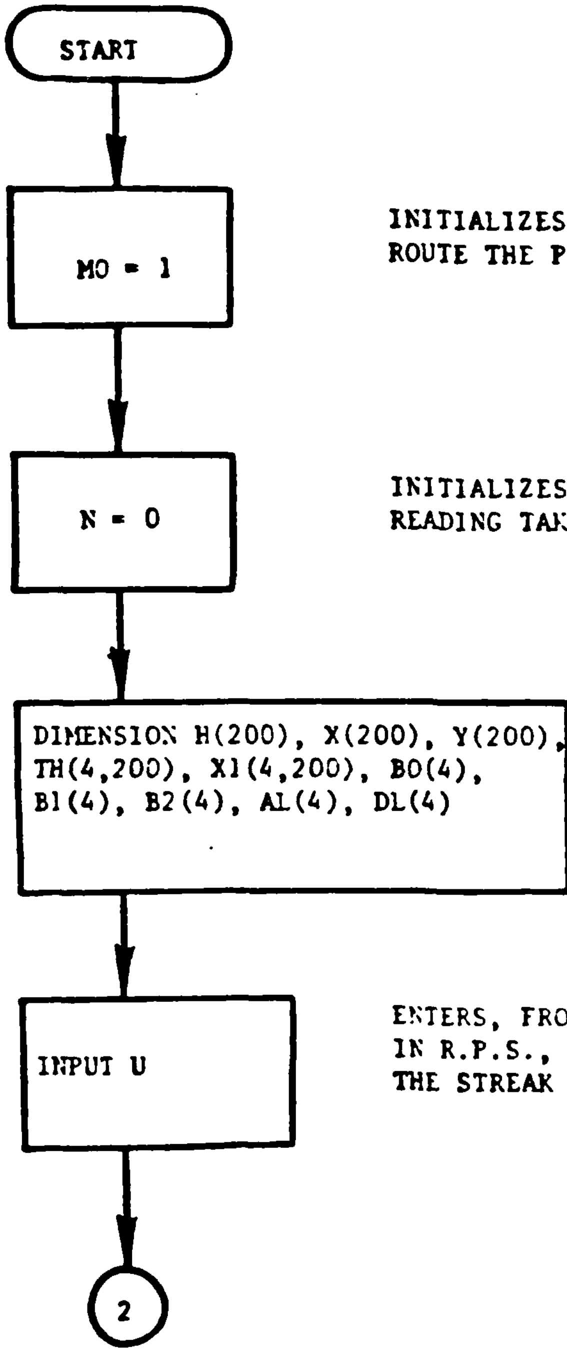
SUBROUTINE VIEWS ARRANGES THE DATA FROM THE THREE VIEWS INTO HEIGHT AND ANGLE MEASUREMENTS

SUBROUTING LMS DETERMINES THE PLANER LEAST-MEAN-SQUARE OF THE TIME THE DETONATION WAVE PASSES THE FILM PLANES



SUBROUTING ANGLES DETERMINES THE WAVE TILT AND ORIENTATION OF THE DETONATION WAVE AT EACH FILM PLANE

SUBROUTINE RETRIEVAL

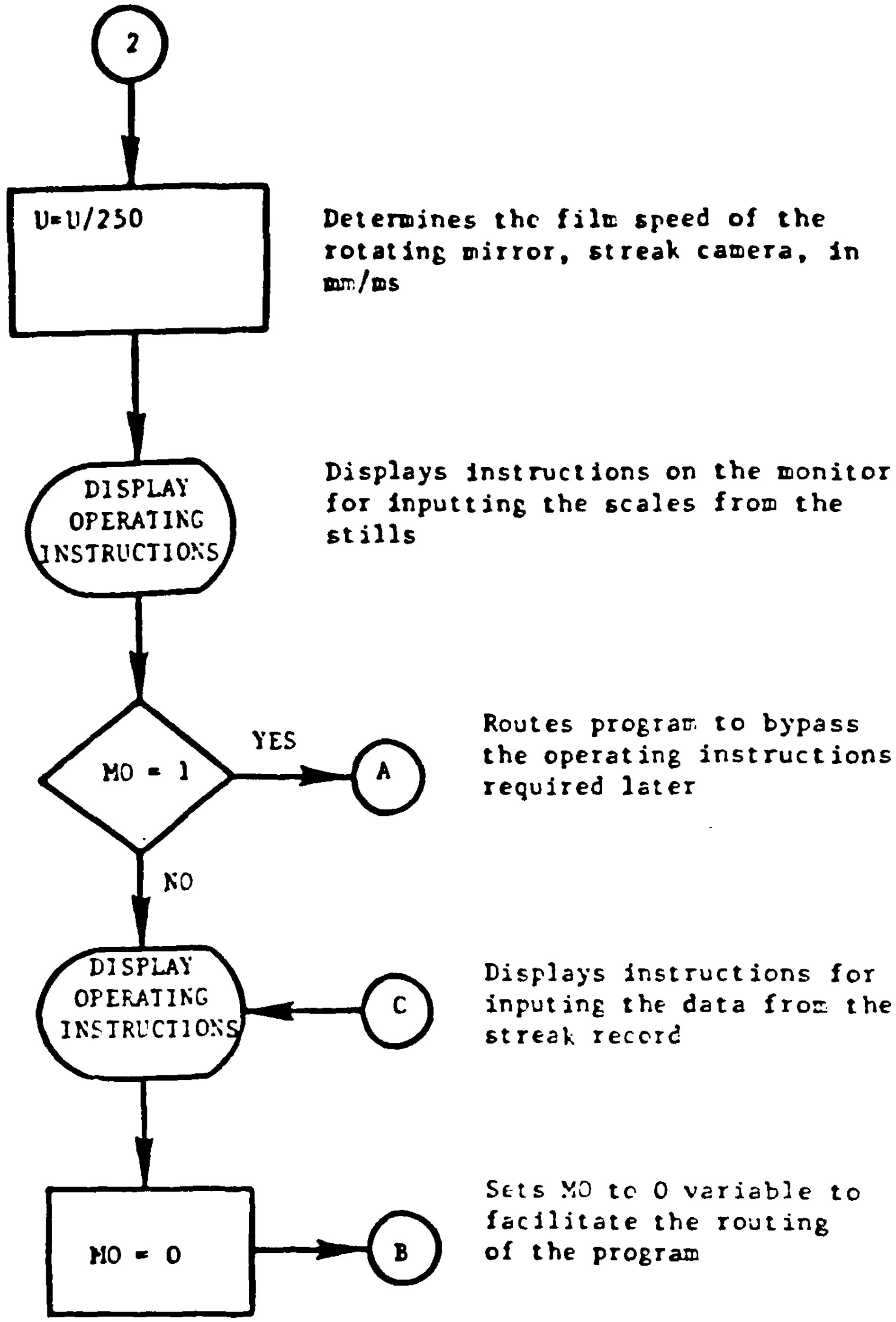


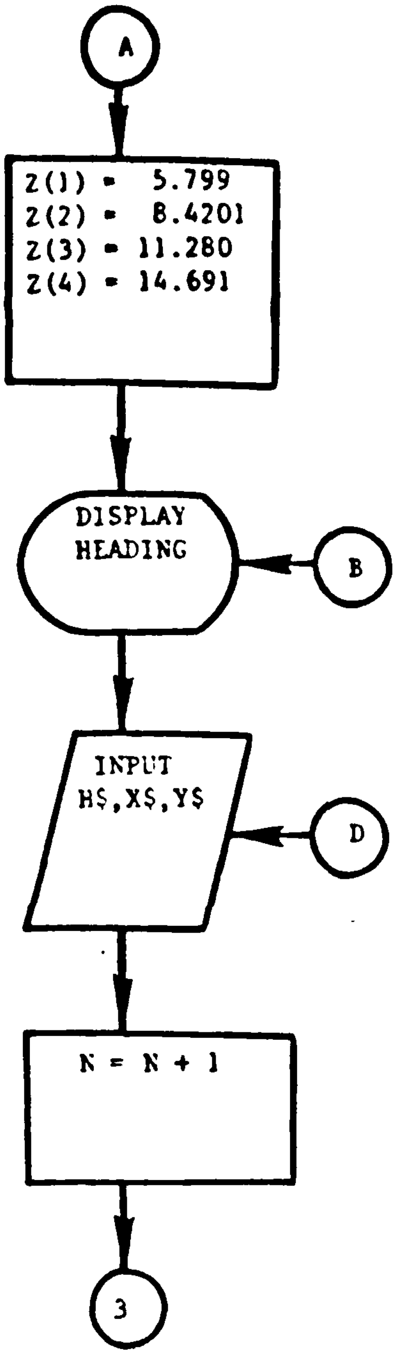
INITIALIZES VARIABLE MO, WHICH IS USED TO ROUTE THE PROGRAM INSTRUCTIONS

INITIALIZES VARIABLE N, THE COUNT ON THE READING TAKEN

DIMENSIONS THE TWO AND THREE VARIABLES USED IN THE PROGRAM

ENTERS, FROM THE KEYBOARD, THE ROTATION, IN R.P.S., OF THE ROTATING MIRROR WITHIN THE STREAK CAMERA


2
U=U/250
Determines the film speed of the rotating mirror, streak camera, in mm/ms
DISPLAY OPERATING INSTRUCTIONS
Displays instructions on the monitor for inputting the scales from the stills
MO = 1
YES
A
Routes program to bypass the operating instructions required later
NO
DISPLAY OPERATING INSTRUCTIONS
C
Displays instructions for inputing the data from the streak record
MO = 0
B
Sets MO to 0 variable to facilitate the routing of the program

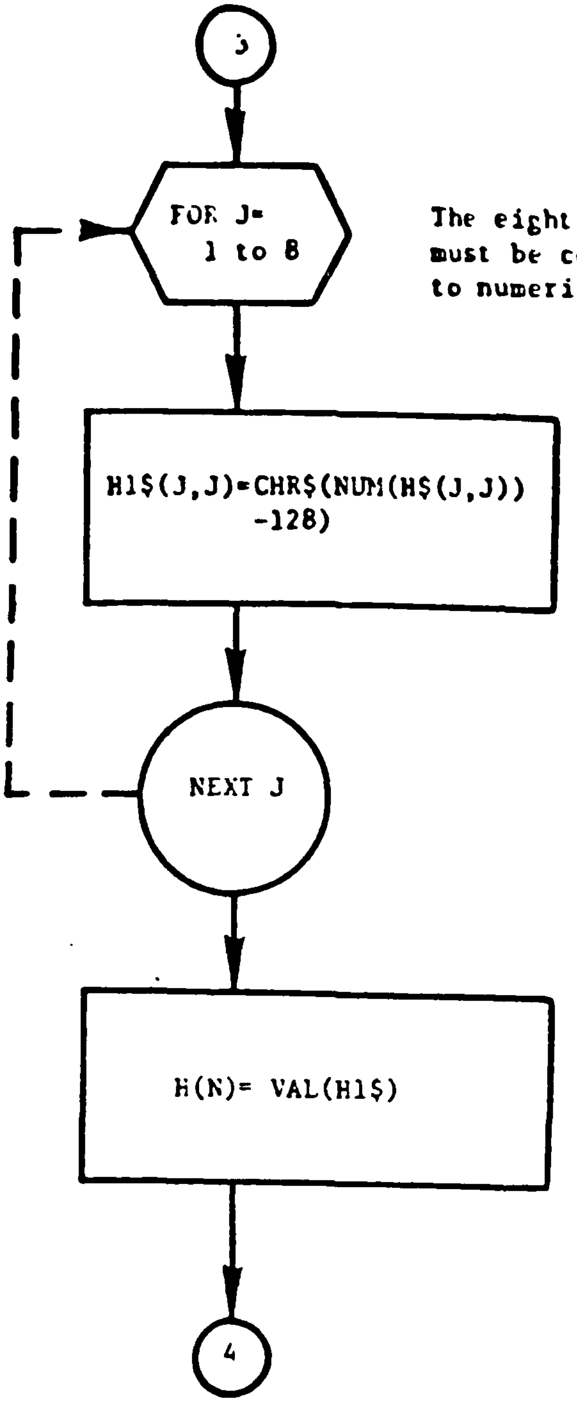


Initializes the measured heights, in mm, of the band on the film wrap

Displays the headings for the print out of the measured points

Inputs H$, the header, X$, the x value, and Y$, the y value, in string format

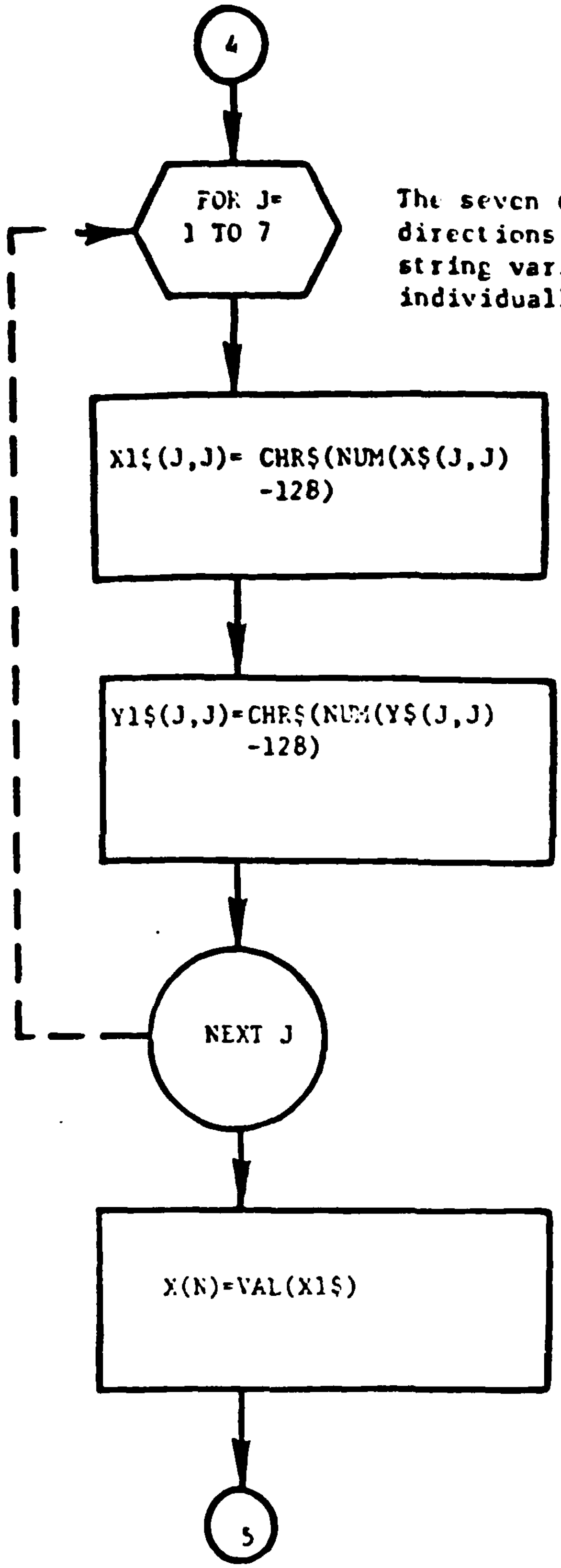
Increment the count on the readings taken



The eight charactures in the header must be converted from string variables to numeric variables individually

The charactures ASC 2 codes are offset by 128. This statement sets the code to the correct individual charactures.

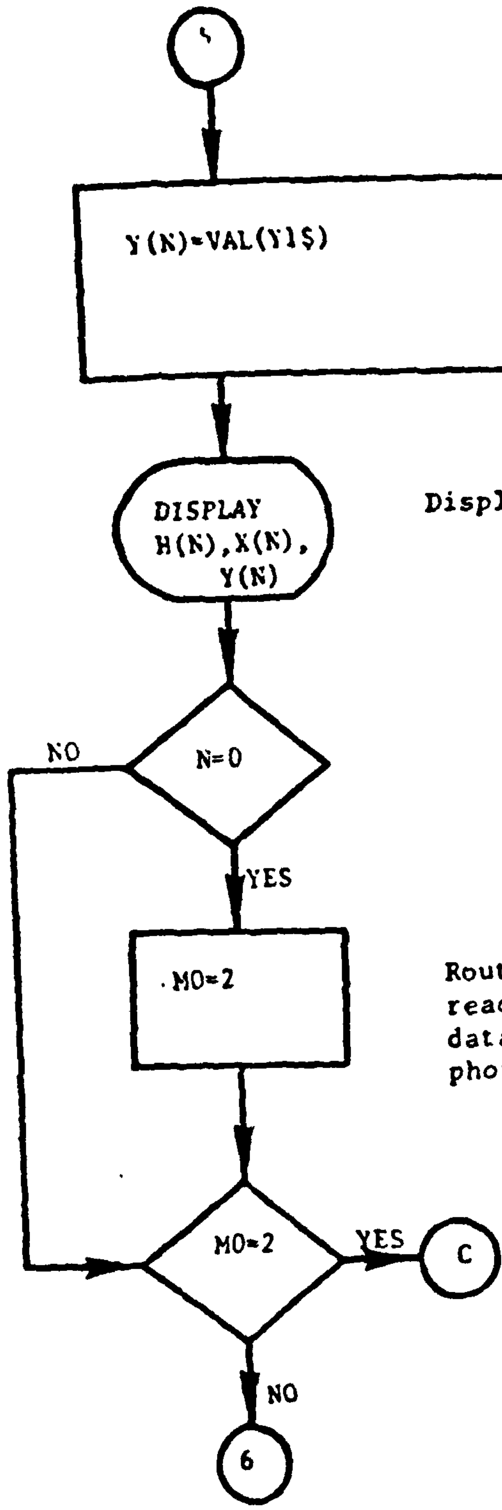
Sets the string character of H1$ to a numeric variable



The seven charactures in the x and y directions must be converted from string variables to numeric variables individually

The charactures ASC 2 codes are offset by 128. These statements set the codes to the correct individual charactures

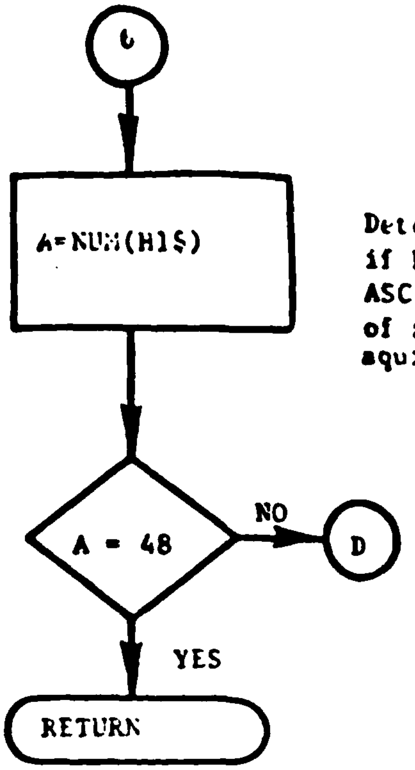
Sets the string characture of X1$ to a numeric variable



Sets the string character of Y1$ to a numeric variable

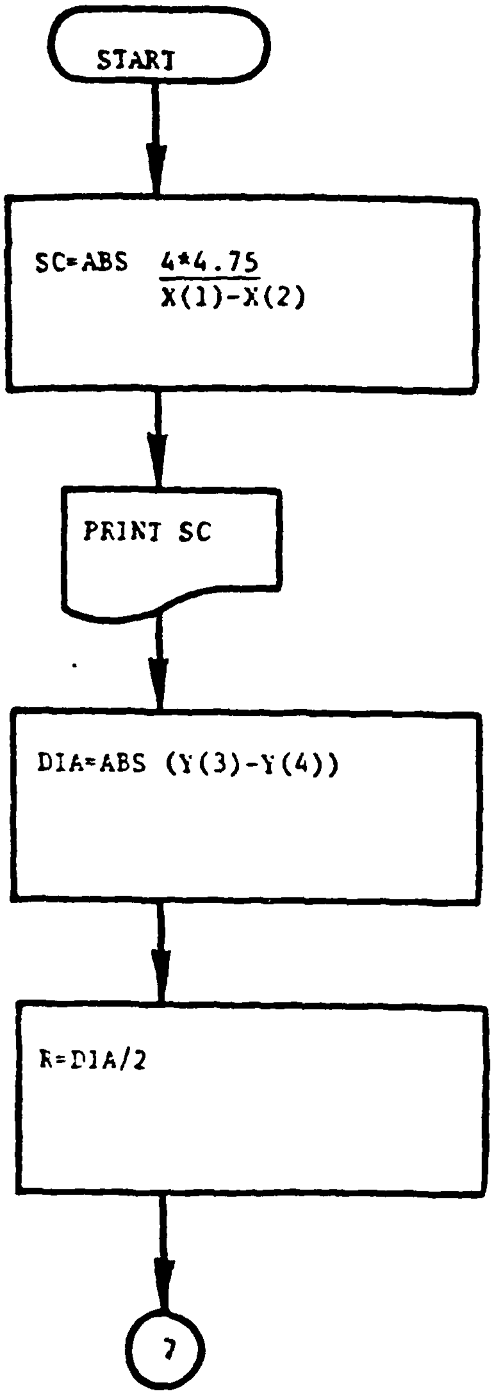
Displays measured data points

Routes the program. After ten readings from the still picture, the data is then obtained from the streak photograph.



Determines the ASCII code for H1$, if H1$ is equal to zero the corresponding ASCII code is 48. A header reading of zero is used to end the data aquisition.

SUBROUTINE SCALES

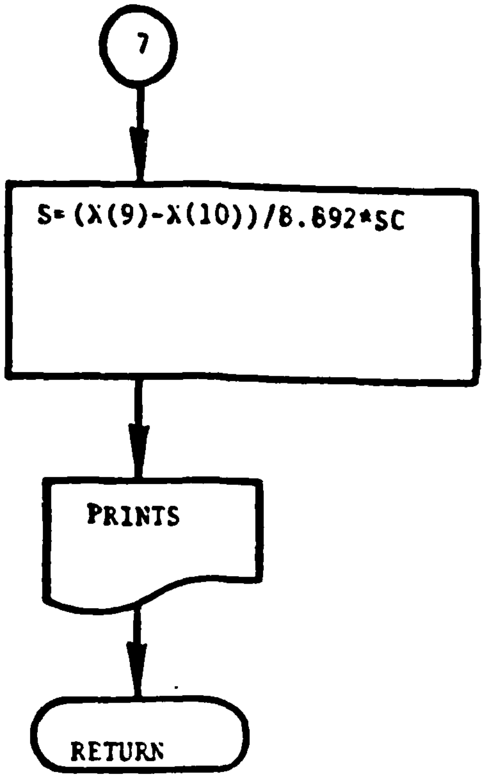


Determines the scale factor between the vanguard divisions and the film dimensions obtained from the standard sprocket hole separation, 4.75mm. Units on SC are mm on film/vanguard divisions

Prints scale factor SC

Determines the scaled diameter from readings 3 and 4, in vanguard divisions

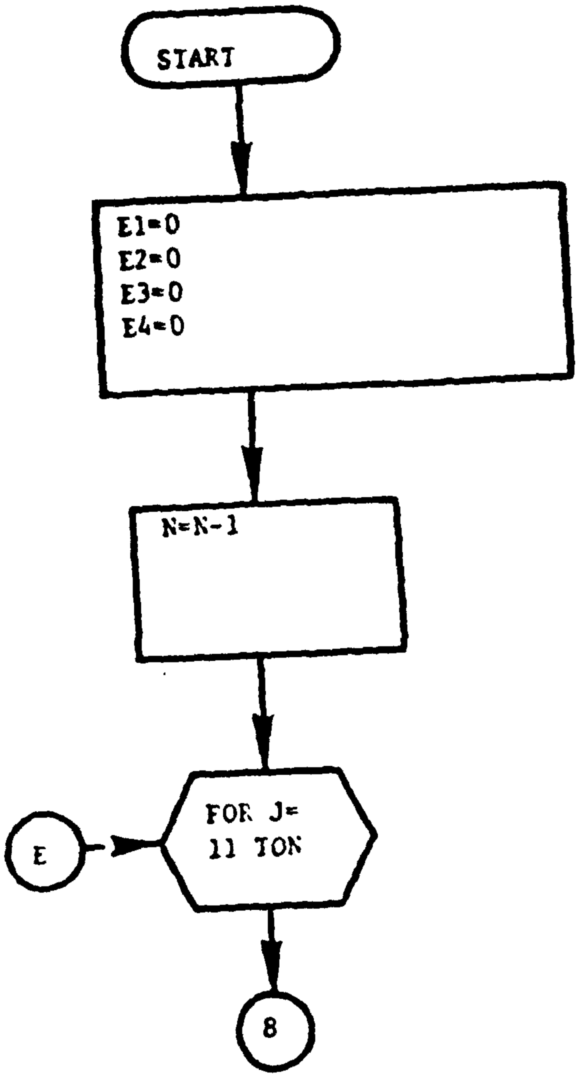
Determines the scaled radius



Determines the scale factor between the film and the test measurements. Units on S are mm on film/mm actual

Prints the scale factors

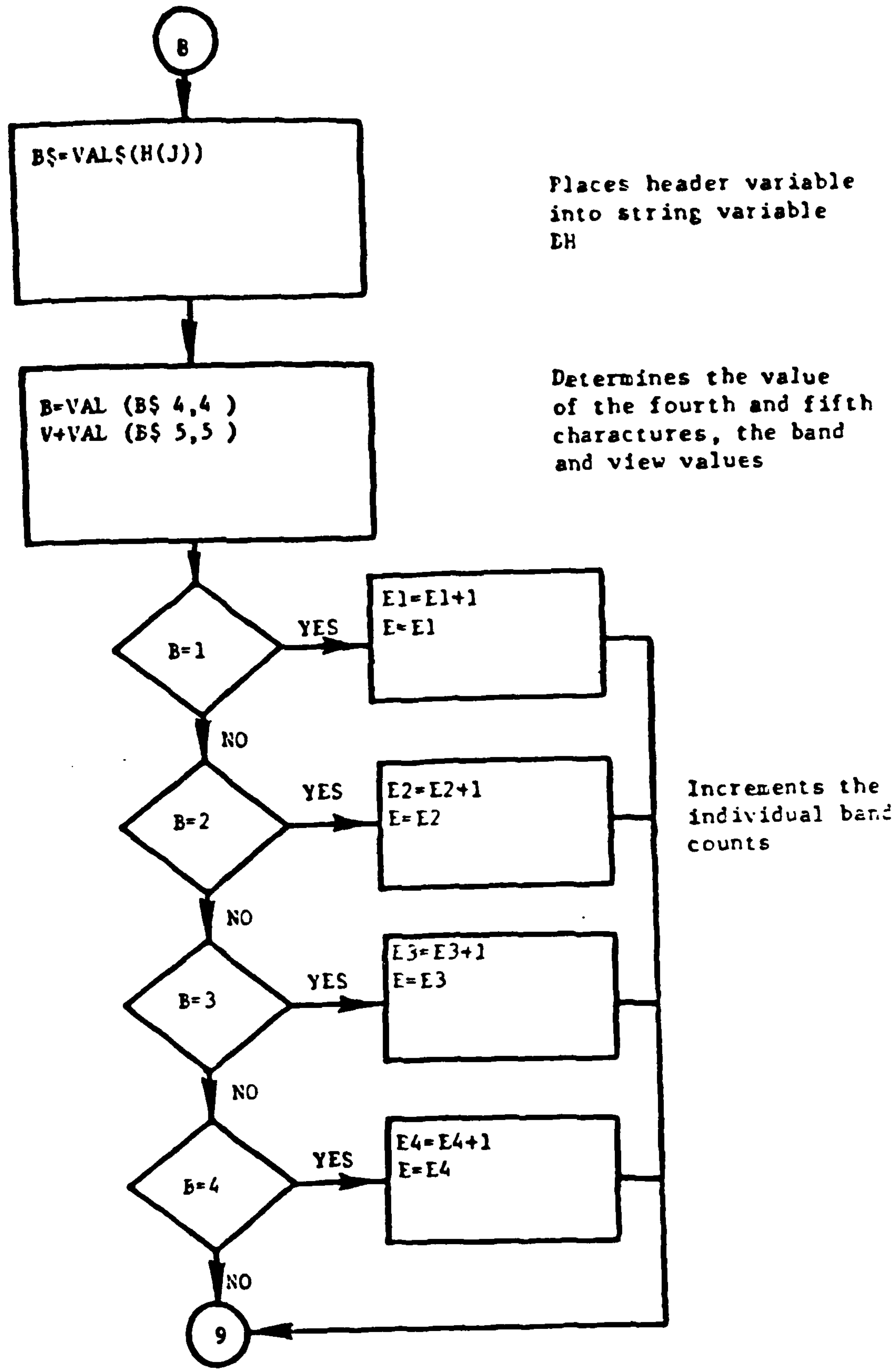
SUBROUTINE VIEWS

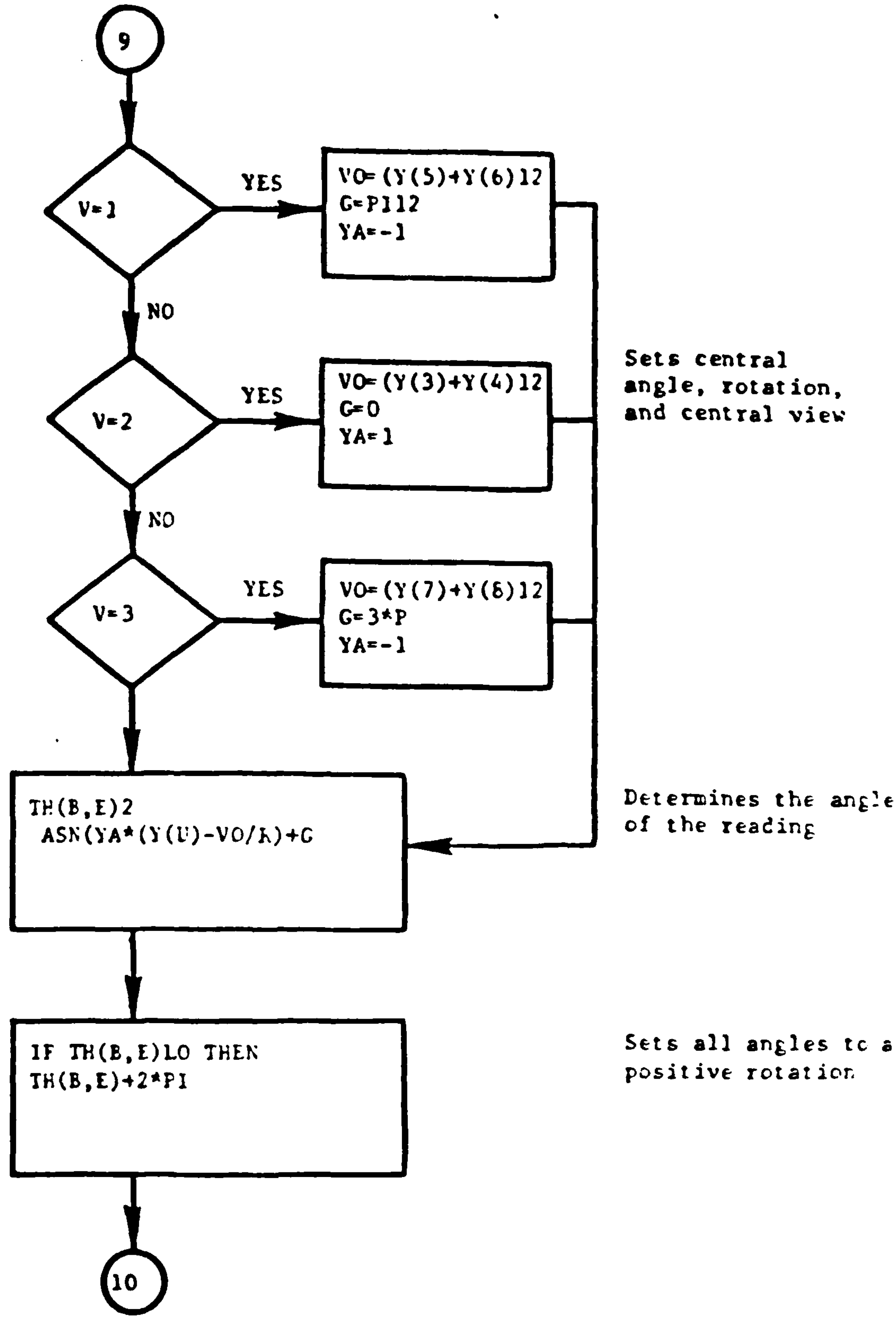


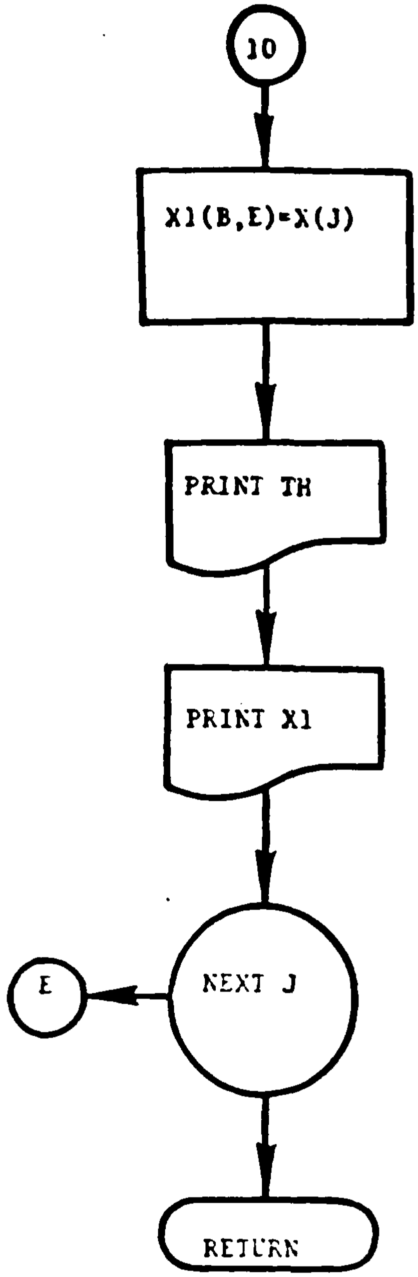
Initializes variables E1 through E4, the counts on individual bands

Reduces the count on the data by one to account for the last reading, which was used the end data acquisition

The first 10 readings were used as scale factors, reading number 11 began the data acquisition of the streak records


B
B$=VAL$(H(J))
Places header variable
into string variable
BH
B=VAL (B$ 4,4)
V+VAL (B$ 5,5)
Determines the value
of the fourth and fifth
charactures, the band
and view values
B=1
YES
E1=E1+1
E=E1
NO
B=2
YES
E2=E2+1
E=E2
Increments the
individual band
counts
NO
B=3
YES
E3=E3+1
E=E3
NO
B=4
YES
E4=E4+1
E=E4
NO
9


9
V=1
YES
VO=(Y(5)+Y(6))2
G=PI12
YA=-1
NO
V=2
YES
VO=(Y(3)+Y(4))2
G=0
YA=1
NO
V=3
YES
VO=(Y(7)+Y(8))2
G=3*P
YA=-1
TH(B,E)2
ASN(YA*(Y(U)-VO/R)+G
IF TH(B,E)LO THEN
TH(B,E)+2*PI
10
Sets central angle, rotation, and central view
Determines the angle of the reading
Sets all angles to a positive rotation

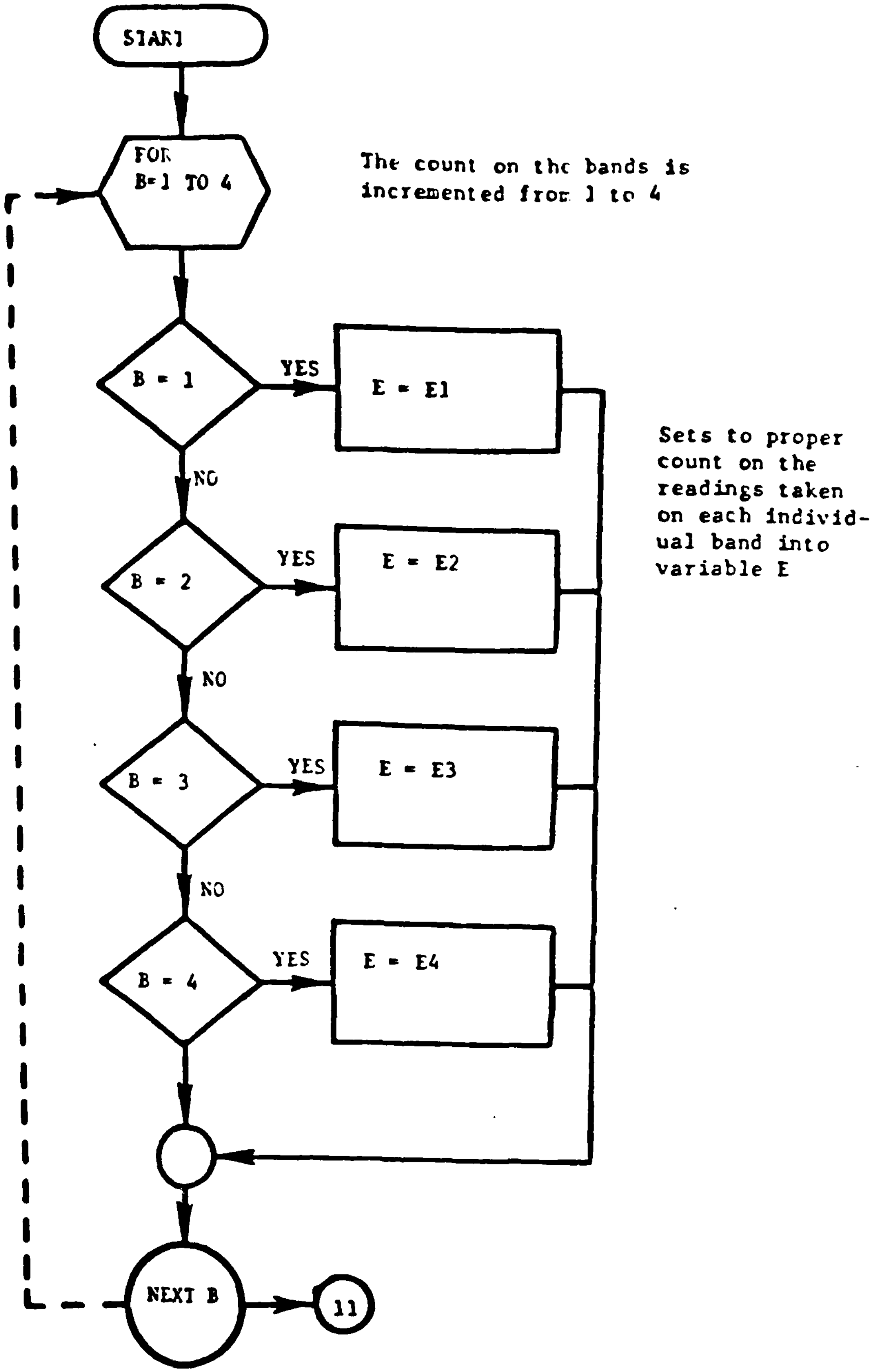


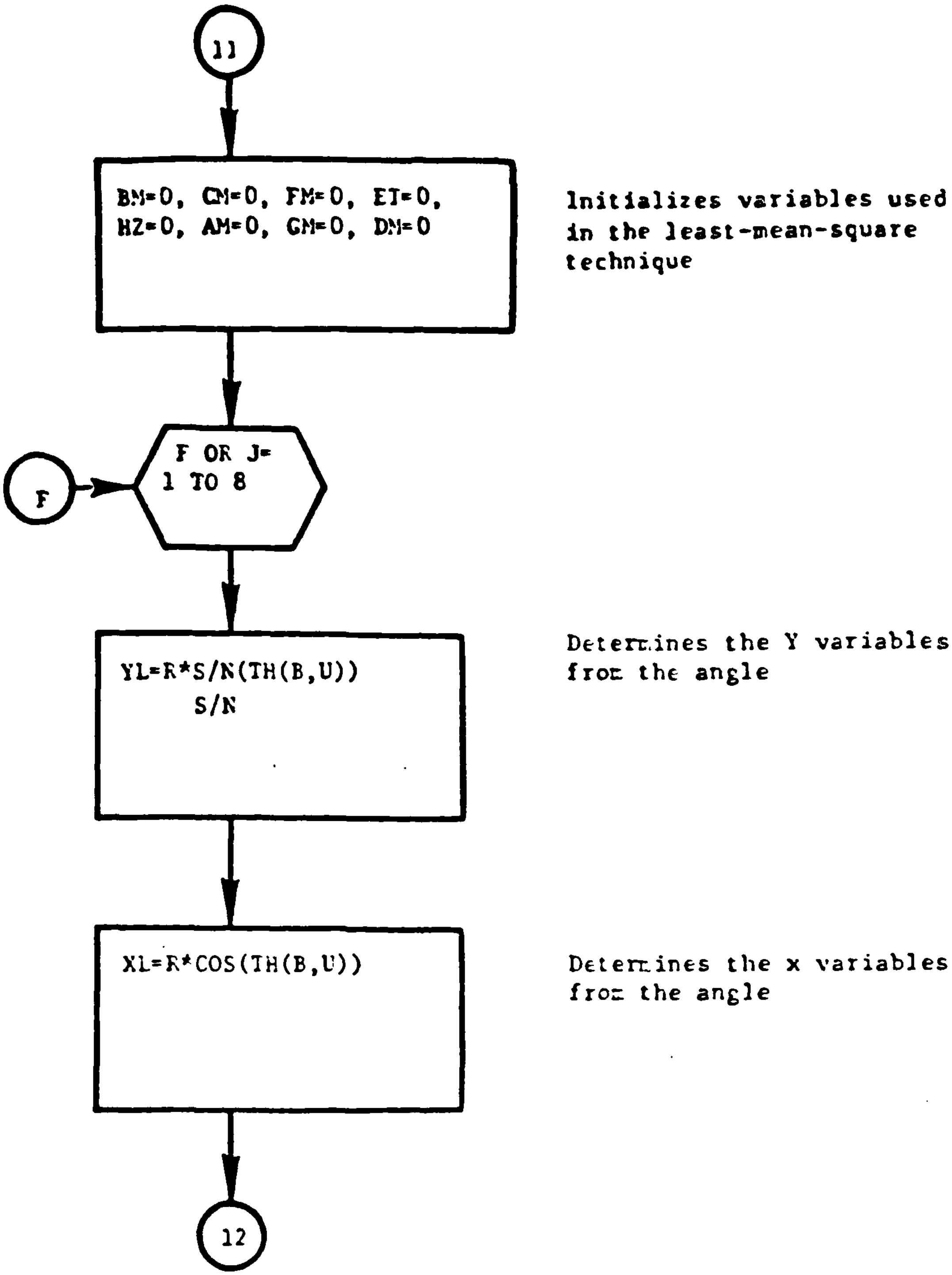
Sets the x variable to the matching two dimensional of the angle

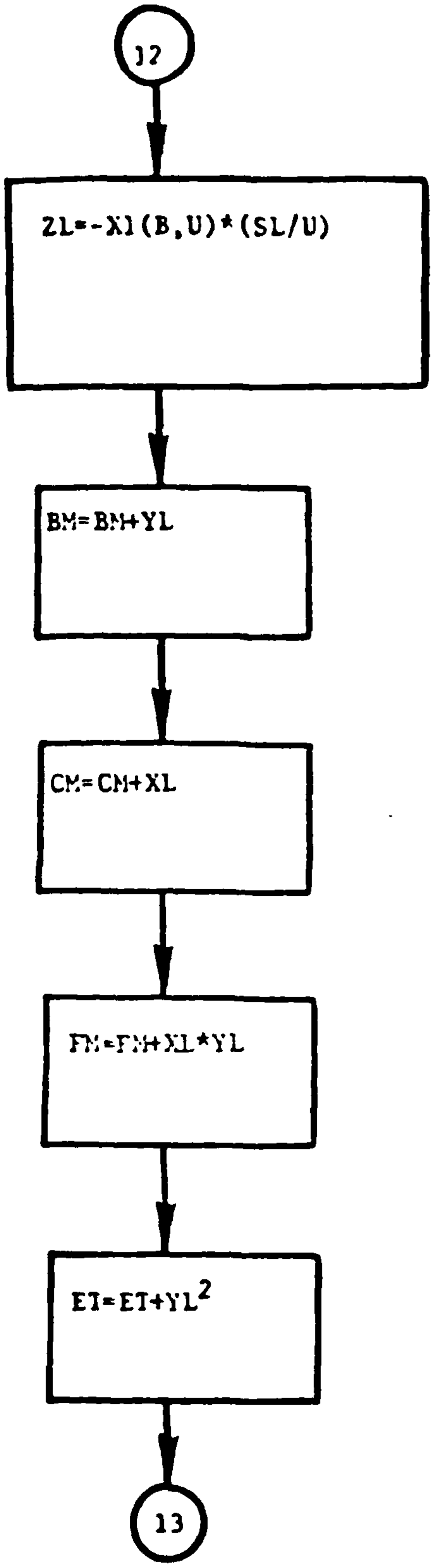
Displays the angle

Displays the x value

SUBROUTINE LN




11
BM=0, CM=0, FM=0, ET=0,
HZ=0, AM=0, GM=0, DM=0
Initializes variables used in the least-mean-square technique
F
FOR J=
1 TO 8
YL=R*SIN(TH(B,U))
SIN
Determines the Y variables from the angle
XL=R*COS(TH(B,U))
Determines the x variables from the angle
12



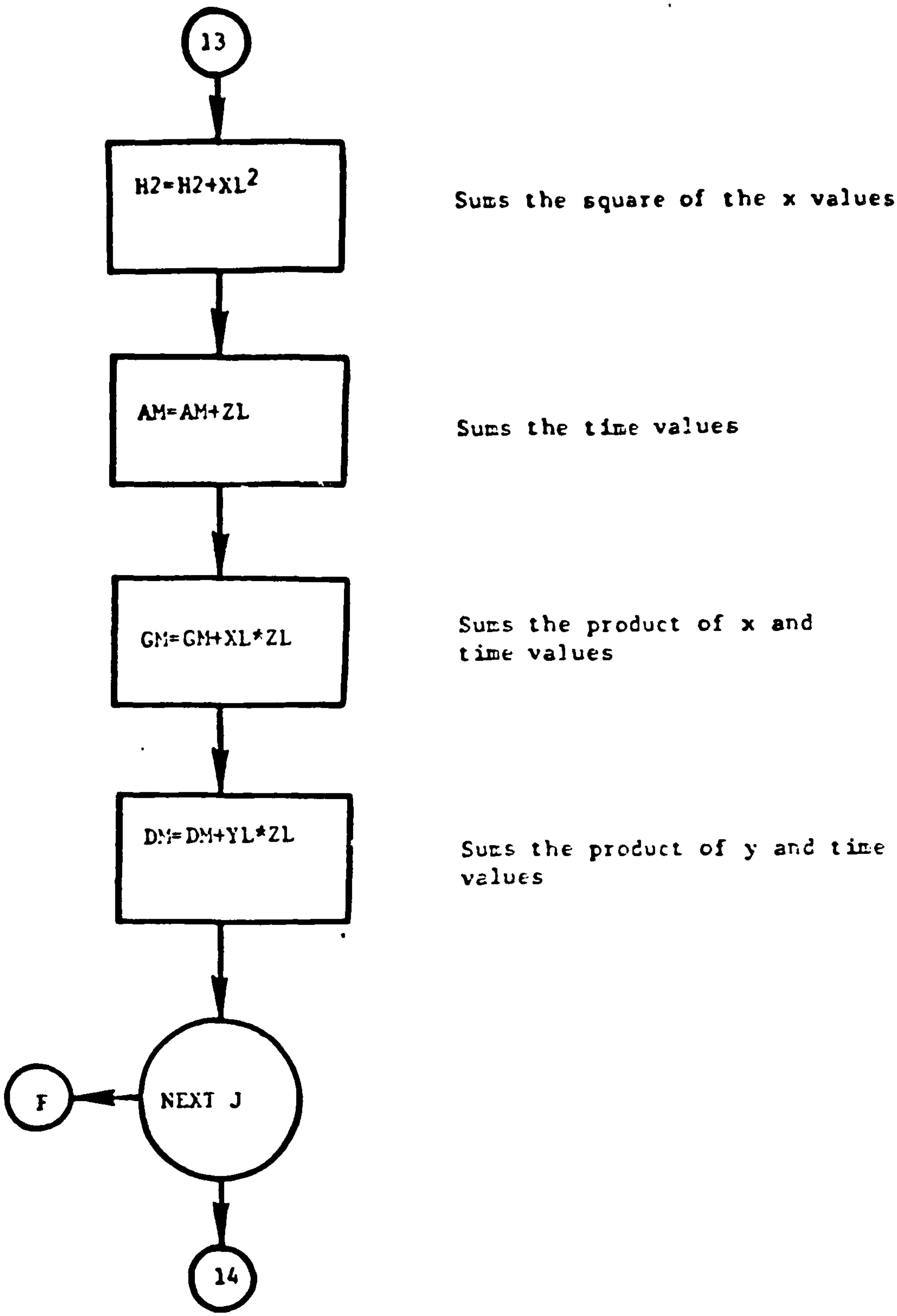
Determines the time of the reading

Sums the Y values a long the individual band

Sums the x values

Sums the product of x and y

Sums the x square of the y values


13
H2=H2+XL2
Sums the square of the x values
AM=AM+ZL
Sums the time values
GM=GM+XL*ZL
Sums the product of x and time values
DM=DM+YL*ZL
Sums the product of y and time values
NEXT J
F
14

14

$$B2 = \frac{\dfrac{GM*BM}{CM-DM} \quad \dfrac{BM*FM}{CM-ET} - \dfrac{\frac{AM}{E} - \frac{GM}{CM}}{\frac{BM}{E} - \frac{FM}{CM}}}{\dfrac{\frac{H2}{CM} - \frac{CM}{E}}{\frac{BM}{E} - \frac{FM}{CM}} - \dfrac{FM-H2*\frac{CM}{BM}}{\frac{BM*FM}{CM} - ET}}$$

Determines the x coefficient of the planar equation

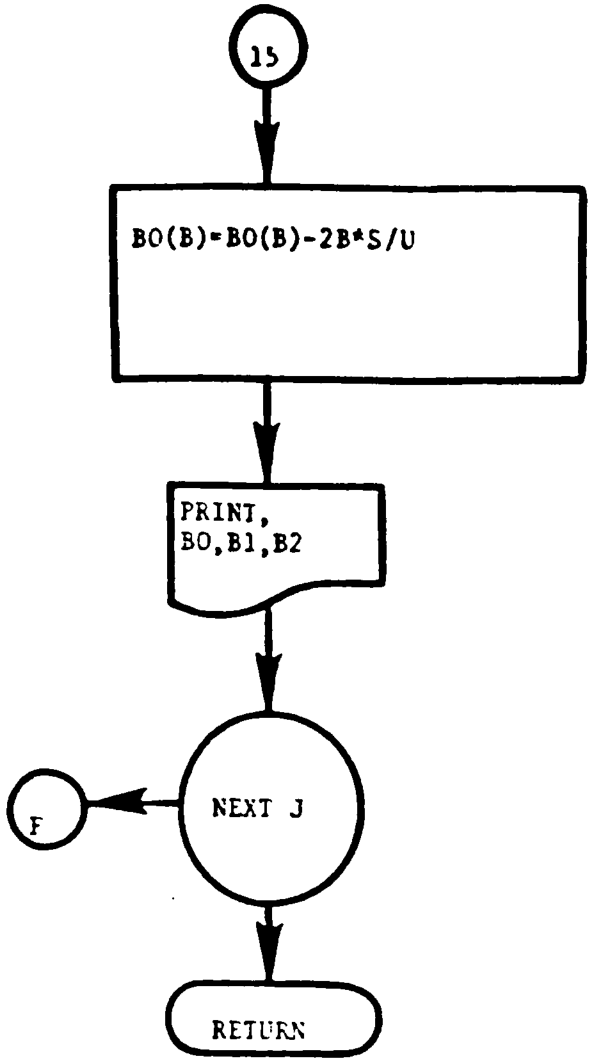
$$B1 = \frac{\dfrac{\frac{AM}{E} - \frac{GM}{CM}}{\frac{BM}{E} - \frac{FM}{CM}} + \dfrac{GMxBM}{CM} - DM \quad HB2}{\dfrac{BMXFM}{CM} - ET}$$

Determines the y coefficient of the planar equation

$$B0 = \frac{\frac{AM}{BM} - \frac{DM}{ET} + B2 \; \frac{FM}{ET} - \frac{CM}{BM}}{\frac{E}{BM} - \frac{BM}{ET}}$$

Determines the intercept of the planar equation

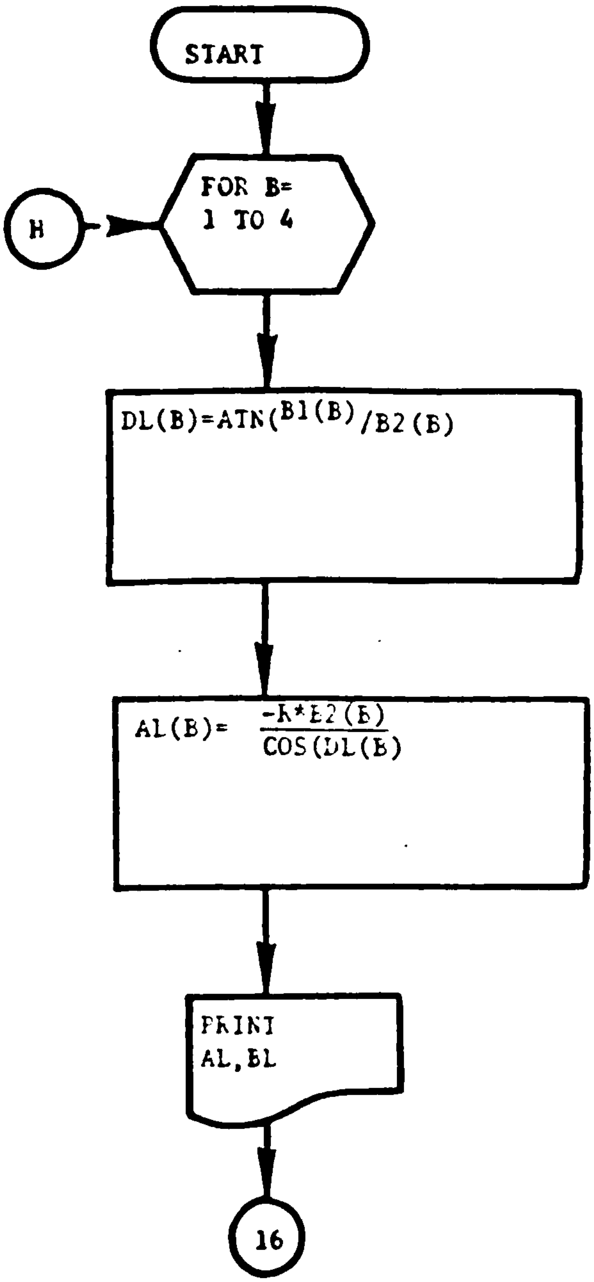
15



Determines the proper intercept, correcting for the variation in band heights

Prints the least-mean-square coefficients obtained

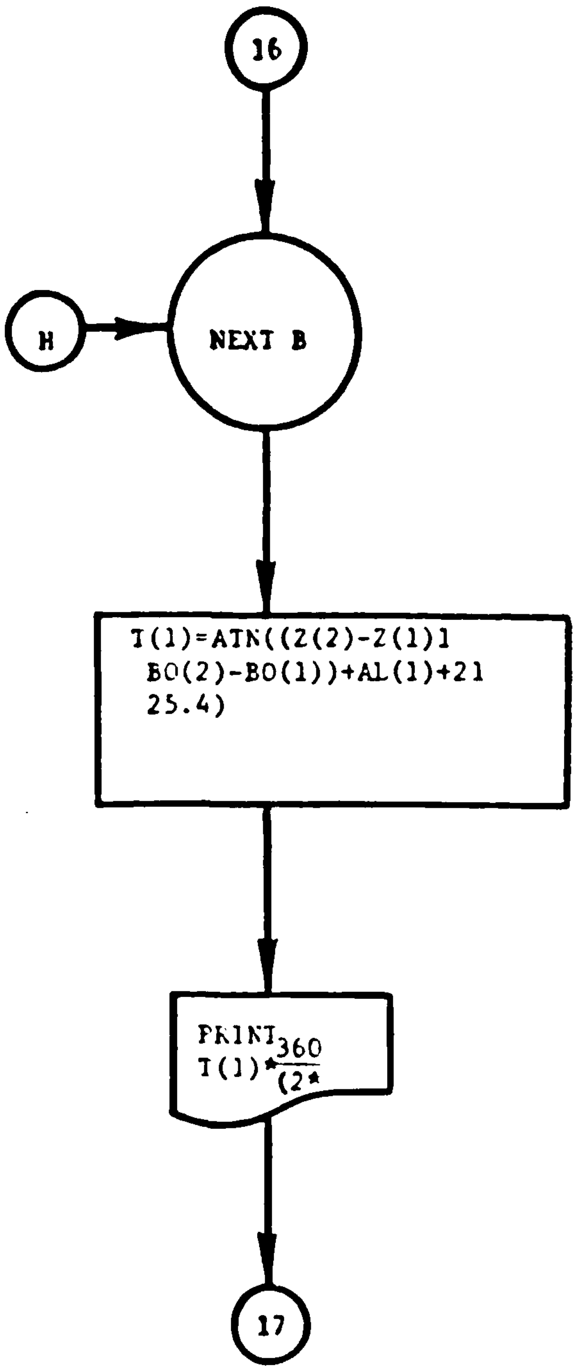
SUBROUTINE ANGLES



Determines the zero angle for the intersection between the cylinder and the time plane

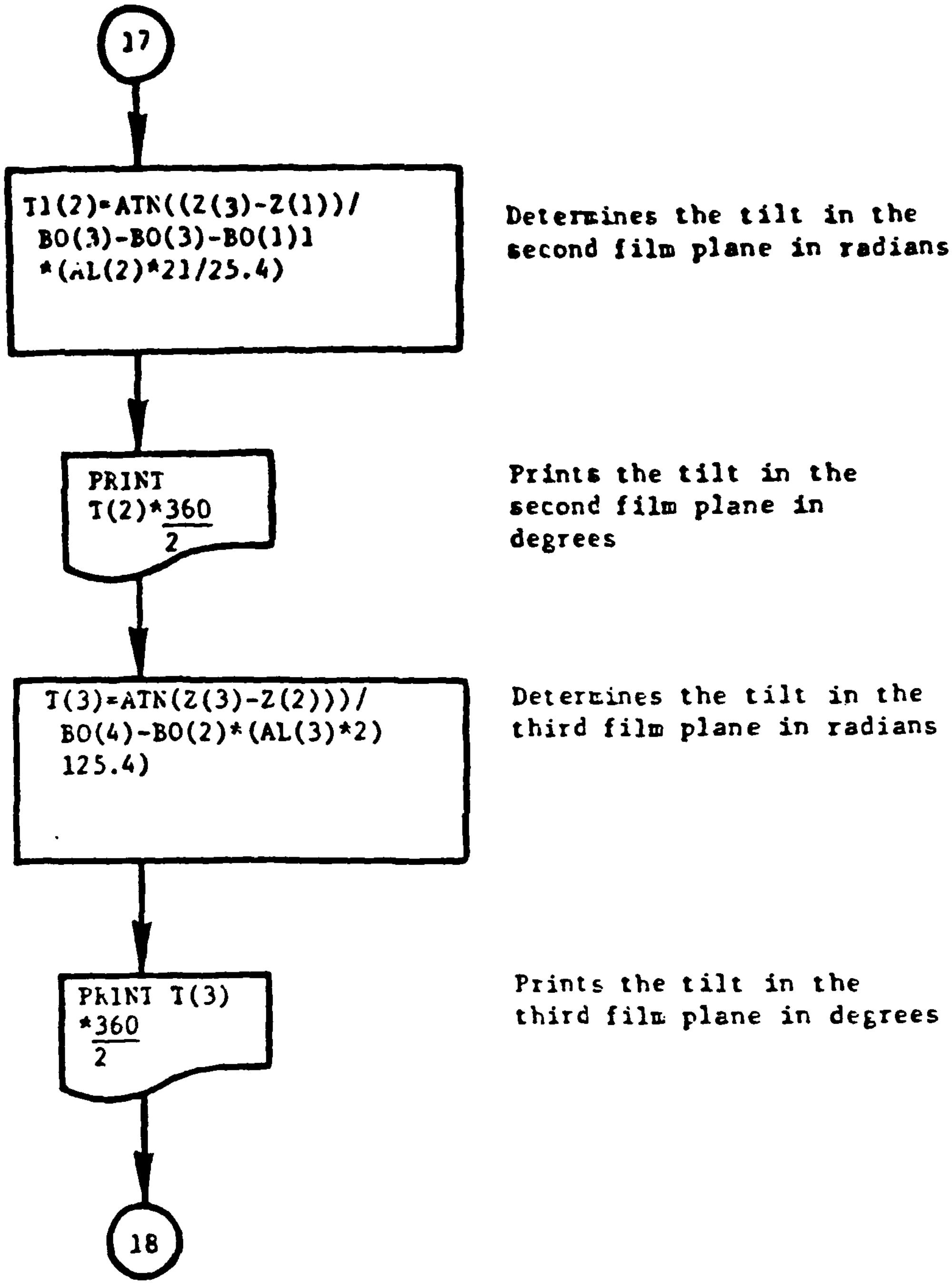
Determines the slope for the intersection between the cylinder and the time plane

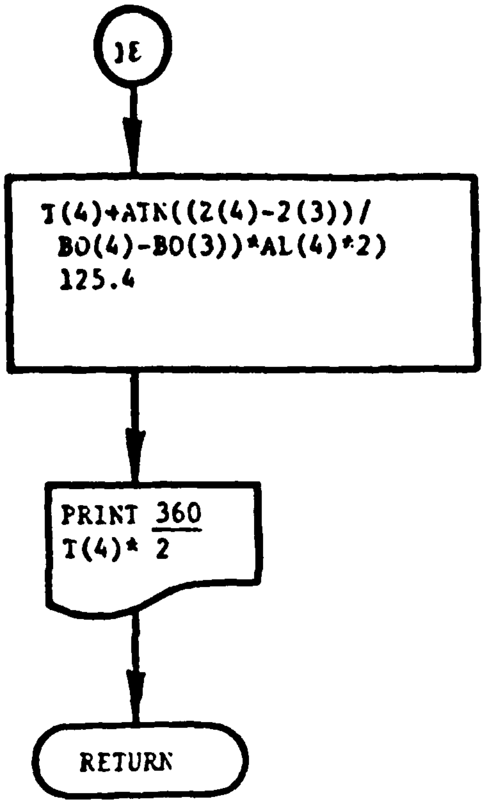
Prints AL & BL



Determines the tilt in the first film plane, in radians

Prints the tilt in the fast film plane, in degrees


17
T1(2)=ATN((Z(3)-Z(1))/
BO(3)-BO(3)-BO(1)1
*(AL(2)*21/25.4)
Determines the tilt in the second film plane in radians
PRINT
T(2)*360
2
Prints the tilt in the second film plane in degrees
T(3)=ATN(Z(3)-Z(2)))/
BO(4)-BO(2)*(AL(3)*2)
125.4)
Determines the tilt in the third film plane in radians
PRINT T(3)
*360
2
Prints the tilt in the third film plane in degrees
18



Determines the tilt in the fourth film plane in radians

Prints the tilt in the fourth film plane in degrees

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